III.

Prof. Phillip delin.

J. W. Lowry sculp.

GEOLOGICAL VIEW OF THE ISLE OF WIGHT.

h. Hastings sand. – l. Lower green sand. – g. Gault. – u. Upper green sand. – c. Chalk. – t. Tertiary.

A GUIDE

TO

GEOLOGY.

BY

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ETC.

" Et mare contrahitur, siccæque est campus arenæ
Quod modo pontus erat, quosque altum texerat æquor
Existunt montes."—Ov. *Metam.*

FOURTH EDITION.

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TO

THE VICE CHANCELLOR

AND MEMBERS OF

THE UNIVERSITY OF OXFORD

This Volume

IS MOST RESPECTFULLY DEDICATED

BY

THEIR DEPUTY READER IN GEOLOGY.

PREFACE

TO

THE FOURTH EDITION.

THE distribution of this Work by former Editions has been so extensive, and since its first appearance so many other introductory views of Geology have been offered to the Public, that its republication might have been indefinitely delayed, did I not think it one of my duties as a Public Teacher, under new conditions, to place in the hands of my pupils what I consider to be a sufficient guide to the subjects of my lectures.

The principal *changes*—which time and the progress of geological research have rendered necessary—in the Work relate almost exclusively to the classification of the lower stratified rocks. The intricate phenomena of the old slaty rocks of Wales have at length assumed a settled order through the long-continued labours of Sedgwick, and the gradual advance of the "Ordnance Geological Survey," under the direction of

Sir H. T. De la Beche. The discussions concerning the age and affinities of the Devonian strata have established the existence, in the south-west of England, of a great series of fossiliferous (partly slaty) rocks below the carboniferous limestone, which, though no where else to be completely paralleled in the British Islands, have found many analogies on the continent of Europe by the labours of Dumont, Sedgwick, and Murchison, and on the continent of North America by the examinations of Professors H. and W. B. Rogers, Mr. Hall, and other eminent geologists, including De Verneuil, Lyell, and other visitors from Europe.

From an early period in his geological studies, the Author found himself impelled, by evidence which came into his possession, to turn a continually growing attention to the affinity of the fossils of the magnesian limestone of England with those of the carboniferous limestones below. His opinion of this strong affinity was stated in 1832 *; the consequences of it on the classification of English strata were expressed cautiously in 1837 †, but positively, and as a part of a general

* Encyclop. Metrop., article Geology (Saliferous System).

† Cabinet Cyclopædia, vol. i. p. 189.

view of the successive systems of organization on the globe, in 1840* and 1841.† The Author's opinion regarding the magnesian limestone has been adopted by Sir R. I. Murchison, and strengthened by evidence gathered in his "Geological Survey of Russia." On his discoveries in the course of this Survey he has founded a new classification of the complicated deposits between the coal formation and the lias, the lower part being separated from the great New Red Series, under a title—Permian System—derived from the Russian district, in which it is most largely developed.

Among other important topics which have lately attracted investigation, I have referred to the recent researches of Professor Edward Forbes (in the Ægean and British Seas), which have rendered to geological reasonings the important assistance of a correct determination of the influences of depth, and the peculiar quality of the water and bed of the sea, on the distribution of marine invertebrata.

Some addition has been made to the notices of the curious investigations usually comprehended

* Penny Cyclopædia, art. Palæozoic.

† Palæozoic Fossils of Devon.

under the title of "Metamorphism of Rocks,"— a subject ever growing in importance.

In connection with the northern drift, attention has been called to the probable refrigeration of large surfaces of the globe during a late part of the Cainozoic Period, which has been thought to have covered with glaciers the mountains of Scotland, Cumberland, Wales, and Ireland, and to have nourished Arctic forms of invertebrata on areas once prolific in races more akin to those of the Tropics.

The question of the heat of the globe has received from Mr. Hopkins an additional elucidation by his investigation of the effect of internal solidity or fluidity on the precession of the equinoxes. As bearing on this subject, the results of the experiments of Quetelet and Forbes on the descent of daily heat and cold, and summer and winter temperature, to small depths below the surface, are concisely stated.

Oxford, 1854.

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A

GUIDE TO GEOLOGY.

PART I.

ELEMENTARY FACTS AND INFERENCES.

DEFINITION OF THE SCIENCE.

GEOLOGY, founded upon observations of the effects of terrestrial agencies—vital, chemical, and mechanical,—upon a grand scale, and through long periods of time, may be taught, by actual demonstration of the phenomena as they are laid open by nature, in mountains and valleys, cliffs and ravines; and by explanations of natural products, and representations and descriptions of the manner of their occurrence. As we cannot transport a pupil to the summit of the Alps, the glens of the Grampians, or the caverns of the Peak; as we cannot at pleasure show him the bold cliffs of

Hastings, Whitby, or Charmouth, the wasting shores of Norfolk, or the extension of new land along the margin of the Adriatic, he must be taught to reason upon these characteristic phenomena by the aid of pictorial or verbal representation. With this view, we found and arrange museums, publish sections and maps, and models, and endeavour, by lectures on these examples and imitations of geological occurrences, to lead the student to the contemplation of the magnificent objects themselves. Could we dispense with these artificial aids, were it possible to compress into a reasonably short geological tour an actual inspection of the most important facts, much of the technical language which is now found so convenient might be dispensed with; many explanations might be spared; the monuments yet remaining of the changes which the earth has undergone would tell their own history, and never require the little aid of words. But the writer and the lecturer must have recourse to other methods; and, by a studied arrangement of representations and reasoning, strive to impress the same truths, with equal force of conviction, which are directly gathered from the more vivid though less regular lessons in the glorious theatre of nature.

The teacher of geology must suppose himself called upon to answer questions concerning both the facts of the science, and the inferences to be

collected from them; and his instructions will be so much the more successful as he takes these questions in the most natural order of their occurrence, and answers them most completely and satisfactorily. In doing this, he is not at liberty to neglect even elementary truths; because if these were passed over, in compliment to such as have made progress in the science, those for whose advantage he is specially interested would be called to the unreasonable task of labouring without tools, of reasoning without data.

The definition of any physical subject or property, or mathematical abstraction, is a description of something real or representative, and is easy; but the limitation of the several fields of research in which the human intellect may employ itself, demands almost a prophetic spirit: it is not the beginning, but the consummation of the study, and perhaps never can be complete. While the intimate union and close dependence of all the physical sciences become daily more and more evident, the difficulty of rigidly defining any one of them is continually increasing.

Having due regard to these considerations, we may say, that it is the province of geology to investigate the ancient natural history of the earth. For this purpose geologists must observe the mineral matter of which the earth is composed, and the manner in which it is arranged; study

the forms of ancient life which it encloses, and the laws of their distribution. For the interpretation of the facts thus gathered, and the physical revolutions thus indicated, they must refer to the known laws which prevail in the actual system of nature. And thus by strict induction they must endeavour to trace the successive physical conditions of the globe, so as to present a correct history of the appointed steps by which it has been brought to its actual state, and made fit for the purposes which it now fulfils.

PROGRESS OF THE SCIENCE.

It is obvious that for the right and full understanding of the phenomena which come before a geologist, he must often refer to the established results of other branches of physical science. Mineralogy must be his guide in ascertaining the ingredients of rocks; chemistry must teach him their ultimate constitution; he must apply to botany and zoology for the examination of extinct plants and animals; and to astronomy and general physics for correct general data within which to confine his inferences. How clearly does this show us the reason why the universally occurring facts concerning the structure of the globe have only within a few years been submitted to any regular investigation, or reduced to general truths! Generalisation in geology can only be

based upon the established results of other more limited natural sciences. Every discovery of laws in chemistry and zoology widens the foundation of rational geology; and so long as men adhere to the method of philosophy taught by Bacon, geology can never again be lost in vain speculations, never again be an arena for discussing delusive hypothesis and unsubstantial conjecture.

Geology, whether regarded as a *history* of the early physical revolutions of the earth, or as the *science* by which this history has been in some degree recovered, has really no other foundation than exact observation and careful induction. It would, therefore, be not a harsh sentence to refuse this title to the mass of mere opinions and conjectures which for some hundred years before the nineteenth century were pompously designated Theories of the Earth. With much better right may the title of geologists be conceded to Strabo and the old philosophers who studied the local phenomena of their countries and proposed limited hypotheses, in agreement with their notion of the laws of nature, than to Burnet and Buffon, whose systems of cosmogony have the air of a philosophical romance rather than of a serious generalisation of facts. The history of the progress of opinions in geology may be useful as a warning to men advanced in geological inquiries, not to reason upon assumptions while facts remain to be

explored, and to repress that impatience of spirit which ever seeks to anticipate observation by the efforts of invention; but the student should, if possible, be kept in impartial ignorance of these conflicting hypotheses, which are too apt to fascinate the young and imaginative mind. For this reason we shall pass silently over the whole subject of the history of theoretical or rather hypothetical geology, and shall proceed to record those positive facts and limited inferences which are the real discoveries in the science.

There is no reason to apprehend that a science founded on interesting facts, which meet us in our daily walks, and are brought to our recollection by the artist, the voyager, and historian, — a science which links itself with every investigation into the material universe, — will ever want cultivators. Its progress is assured, and all civilised people will contend for the honour of directing its march of discovery. It has been, and still is, the just boast of our country, that in variety of research, in extent of discoveries, and in sound and valuable generalisations, the geologists of Great Britain are second to none. The English system of geology as applied to the older rocks has been adopted over all Europe, and the labours of English geologists have still a decisive influence on the progress of the science. Whether this shall be the case in future years must depend

upon the industry of succeeding observers. There is, however, no reason to despond on this subject: no region of the earth is more prolific of geological phenomena than the British Islands; no other country offers equal advantages or greater inducements for exploring them. The principal difficulties which impeded the progress of our predecessors have been removed by their perseverance; they have extricated some leading truths, corrected many errors, conquered many prejudices, fixed the science upon a sure basis, and obtained for it universal attention. Undoubtedly vast fields of inquiry are yet unexplored, and many labourers are required to bring them into cultivation; but whoever now commences this study may do so with the advantages of knowing what results have been arrived at, how to direct his researches toward the points which promise the richest harvest of discovery, and where to obtain aid from collateral branches of knowledge.

To place before the student these results in a regular order, and to instruct him in the processes by which they have been obtained, is the aim of the following pages.

ARRANGEMENT OF ROCKS.

For this purpose we shall observe the positions and arrangement of rocks in the exterior and visible parts of our planet, generalise the phe-

nomena which they present, examine the history of their included animal and vegetable reliquiæ, and, from the whole of this evidence, attempt a connected outline of the leading physical changes which have happened to the earth, and have left traces accessible to human scrutiny.

The depth to which it has been found practicable for man to penetrate the crust of the earth, is but a small part of that to the knowledge of which, in some cases, the power of induction has enabled him to attain. The deepest mines in Great Britain (Monk Wearmouth, near Sunderland, Consolidated Mines, Cornwall), descend to little more than three-tenths of a mile: the deepest mine in the world (Kitzpühl in the Tyrol, 2,764 feet), to little more than half a mile. We shall see hereafter, that owing to the way in which the materials of the earth are arranged, the structure of the crust of our globe is really known, in particular instances, to a far greater depth. At present, limiting our statements to the extent of actual observation, we shall show what is the arrangement of the materials of the earth, as they are seen in wells, pits, and mines, on the sides of rivers, on the slopes of mountains, and in cliffs against the sea.

There is a circumstance to be attended to in the very outset of this inquiry, which it is of much importance to understand properly. The *actual*

surface of the earth is occupied by soil (which is sometimes nothing else than the decomposed substance of the rocks beneath), by gravel and sand, and particular sorts of clay, which have been drifted by wind and transported by superficial currents of water, and deposited in much confusion upon the solid fabric of rocks. In all the following statements concerning the parts of the globe near the surface, this irregular and variable covering is neglected, and the reader is supposed to look upon the naked skeleton of the globe, stripped of its fertile soil, and all its softer and looser investments. The soil and other loose materials of the surface of the land are worthy of curious and diligent research, and have, indeed, amply rewarded inquiry; but the study of them belongs to another part of the subject. We learn little concerning the *structure* of the earth from these irregular accumulations, which, in fact, only mask and conceal its original features, though they teach very remarkable truths concerning the revolutions which have affected its surface. (See fig. 2.)

There are two principal conditions of arrangement, to which all the lesser appearances observable in the crust of the earth are subordinate.

In the first case, the bounding surfaces of the rock are parallel, or nearly so, and extend to great distances, so as to include between them a

tabular mass or layer of rock, which is technically called a bed, or *stratum.* Several such beds or strata may be laid parallel one to another, and thus constitute a stratified *formation.* These strata may be of the same or of different thicknesses, of the same or different chemical qualities; they may include the same or different organic exuviæ, or be wholly devoid of them. All these circumstances are worthy of remark; but the important thing to be attended to in the first instance is, that *the rock is stratified.* (Fig. 3. *b.*)

In the second case, no such stratification is observable. Many rocks are columnar in structure; some are formed in large lenticular or spherical concretions; others have a peculiar internal cleavage; others are amorphous. All these and many more circumstances are important; but the first thing to remark is, that *the rock is not stratified.* (Fig. 3. *a.*)

STRATIFIED ROCKS.

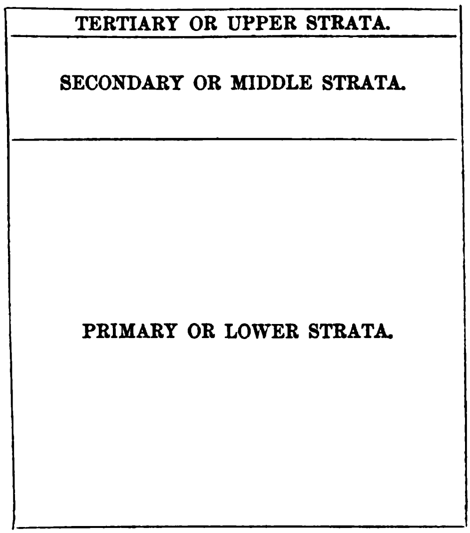
A useful notion of the leading appearances of stratification is most easily acquired by examining the eastern, southern, and western coasts of England, where the cliffs present what is called *a natural section,* and frequently display the edges of more than one kind of stratified rock; sometimes many kinds, as limestone, sandstone, and clay, are placed one upon another, in a certain

order, like the leaves of a book. The order of occurrence which the edges observe in one part of the cliff is found to be the same in another part; so that these strata form a series of terms, whose relative place is known. In other countries, other and quite different rocks may be seen, but these likewise show amongst themselves a settled order of succession. Exactly the same conclusion results from the experience of miners and colliers, well-sinkers and quarrymen: it is confirmed by examination of mountain slopes, and valleys; so that we may state it as a general truth, that the strata, wherever they occur, by the sea-coast or in the interior of the country, are superimposed on one another in a constant order of succession, and compose one regular series.

It is observed that the bounding surfaces of the strata, which we shall henceforward designate planes of stratification, are seldom quite horizontal, but declining into the earth, so that along many lines of coast their edges rise from beneath the water to some height above it. In the interior of a country, in the same manner, the same or other strata decline in some direction, east, west, north, or south, so as in that direction to go deeper and deeper. This declination, or *dip*, of the strata is sometimes at a considerable angle to the horizon, but generally it is so moderate as 1 yard descent in 50 yards' length. All the strata in the same

district commonly dip in the same direction. The exceptions to this general law arise from particular and well-known, often local, causes. If, then, the circumstances of the country are favourable, we may see in the cliffs of the coast, or along the valleys and hills of the interior, the several strata rise in succession from the deeper parts of the earth, and end at the surface. We can notice their order of succession, measure the thickness of each, and combine our observations into an artificial diagram, which shall represent truly what *would be* the appearance, if we could perform the operation of cutting the earth along the given line to the required depth. Such a diagram is called an *artificial section.* By prosecuting these researches, until we have found the true place of each stratum in the general series, and its thickness, we come to form a *general table* or *section* of the whole series of strata existing together in any one country. Though we may not be able at any one place to see more than a few of these strata exposed, yet by examining them as they successively rise to the surface of the earth, and adding all their thicknesses together, we learn the *aggregate thickness* of the whole mass of strata under any region; the depth, in short, which must be sunk in order to penetrate through the whole series, beginning with the uppermost. In England we may call this known thickness three,

five, or more miles, according to the situation. The following diagram shows how much greater a proportion of this thickness is occupied by the oldest, and how much smaller belongs to the youngest of the three grand groups of strata, in the British Isles.



The strata which are comprised in these great divisions will be described in future pages. (See Part III.)

A knowledge of the exact series of strata existing in any given district may be easily acquired, and it has, in fact, been possessed by practical men

in almost every local district where natural sections can be observed, or mines and collieries are extensively wrought. But until Werner and Smith, independently of each other, compared the stratification of different countries, and discovered laws of accordance in the series of strata over large tracts of the globe, the local knowledge of miners and colliers, for want of combination, was of small geological value, and often led to absurd hypotheses. Any one who possesses this local knowledge is, however, immediately in a state to follow the steps of the great geologists above named. In the first place, he must accustom himself to consider the series of strata, not only as they succeed each other in the earth, but also as they appear on the surface; he must not only draw a section, but outline or colour a map.

On the map, fig. 4., given as an example, some of the principal masses of strata are marked by appropriate shades; the chalk, which is the uppermost term of the middle or secondary series, extends from Flamborough Head through Yorkshire, Lincolnshire, Norfolk, Suffolk, Hertfordshire, Wilts, Dorsetshire, &c. Parallel to it stretch the oolitic and lias rocks in an uninterrupted range from the coast near Whitby, through Yorkshire, Lincolnshire, Northamptonshire, Gloucestershire, and Somersetshire, to Dorsetshire. Nor is the area of these strata limited to England, for they

cross the Channel, and occupy large spaces, in the same order of succession, on the continent of Europe.

Hence we learn that not only the principle of stratification is very extensively recognised over the globe, but also that some particular sets of strata are continuously traceable over large tracts, preserving the same relative position on the surface and in the interior; so that a general table of their order of superposition may be drawn up, which shall apply, allowing for local peculiarities, with equal truth to every part of their ranges, as, for example, to all Europe. Thus we rise to a general principle of great importance, by which we may hope eventually to connect the results of observations of stratified rocks over the whole globe into one harmonious system.

This continuity of the strata is not to be understood of every locally observed member of the series, nor even sometimes of every set of beds of the same kind; for some of these are the effect of very limited causes, and all of them are liable to local variation. Hence it happens that in some countries certain strata are wholly wanting, and others are so much altered that the same parts of the series assume totally different characters. No sets of strata are continuous over the globe; there are no *universal* stratified rocks; but

yet it is true that certain groups of these stratified rocks, consisting, for example, of particular kinds of limestones, sandstones, and clays, or of certain gneiss rocks, mica schists, and slate rocks, are so extensively traceable as to give us reason to conclude that very extensive and uniform operations of nature were concerned in their production.

The organic exuviæ which are found in the stratified rocks offer a wide field of inquiry, from which already rich and valuable results have been gathered. This is not the place to develop that magnificent subject further than to show *what* these remains are, and how they can be brought to afford evidence of revolutions which the earth has undergone. Both plants and animals have left monuments of their existence and traces of their forms in the earth. The ligneous, vascular, and sometimes the cellular parts of plants abound in the earth, and the leaves are so perfectly retained that an exact comparison can be instituted between them and recent vegetables. Of animals generally the soft parts are not often preserved in the earth, but the bones of reptiles and other vertebrata, the hard coverings of crustacea, the shells of mollusca, the stony and even membranous coverings, supports, and cells of zoophyta, are abundant. Generally speaking, the fossil species both of plants and animals are not identical with existing kinds; often they belong to different

genera, and sometimes admit of no close resemblance with any living form. In certain strata of the least ancient date, both plants and animals occur not distinct from existing species. Fossil plants and animals do not exist in all the strata, nor everywhere in equal abundance in the same stratum or set of strata. They are not confined to any particular kind of mineral matter; they are not always present in rocks of a certain kind; nor, except in a few instances, always absent from other rocks. These remarks are sufficient for the present course of argument.

UNSTRATIFIED ROCKS.

The *principle of stratification* is universal; that is to say, in every country of sufficient extent stratified masses occur in a certain consecutive order; and in many very large districts removed from the mountains none but the stratified rocks are seen. Any one whose notions of the structure of the earth were drawn from observations in south-eastern parts of England would certainly suppose, as Werner did, that all rocks were stratified. On the contrary, the inhabitant of mountainous regions finds a great variety of rocks, such as granite, syenite, porphyry, &c., in which no trace of stratification can be seen,—many others, like gneiss and slate, in which this structure is so anomalous as to convey to his mind a very indis-

tinct notion of its true nature. These insulated observers can therefore hardly understand each other; and it is no wonder if theories based on their observations are found to disagree.

In many countries, however, the stratified and unstratified rocks occur together; and it is then seen that while the former follow a regular arrangement, and lie nearly parallel to the earth's surface, the latter appear in irregular, often unconnected, masses beneath all the strata, or protruding through them in insulated peaks, or traversing them in vertical masses called dykes, or penetrating them by veins. Not only have they no constant relation to the stratified rocks, but they have no constant relation to one another, either of position or mode of occurrence; so that it is impossible to form anything like a regular series of them. Hence they are very properly called by D'Halloy *roches hors de série.*

Further examination shows that the mineral ingredients of which the stratified and unstratified rocks consist, are either very different or in a very different state. For while the stratified rocks, amidst all their variations of colour, hardness, and chemical constitution, can be described as limestone, sandstone, clay, ironstone, coal, &c., the unstratified rocks are wholly different, and consist of minerals of many kinds, variously aggregated together. The former are often composed of

attrited grains, the latter of perfect crystals; the former generally contain organic exuviæ, the latter almost never. Whenever these appear at the surface, the former are more or less disturbed and confused in position: and the result of comparative examinations upon them is invariably found to be a full belief that they were produced by different causes acting independently, and, in most instances, at different periods.

We shall now class the phenomena presented by these rocks in such a form as to exhibit their distinctive peculiarities, and put them in comparison with the modern effects of natural agencies upon the globe. In this way we may expect to learn the causes concerned in their production.

ORIGIN OF THE STRATIFIED AND UNSTRATIFIED ROCKS.

In the modern system of nature we recognise two great agencies employed in producing changes on the face of the globe,—WATER, which wastes away, grain by grain, the elevated portions of the land, and deposits its spoils in lower situations, thus ever tending to equalise the levels of the surface;—FIRE, which raises matter in masses from the interior of the earth, and thus tends to increase the inequalities of its surface. Both of these agents act chemically; water dissolves, heat fuses. Both also act mechanically. The mecha-

nical effects of water depend on the general force of gravitation, and ever tend downwards, so that the lowest part of any aqueous deposit is the oldest; but the mechanical force of heat is independent of gravitation, and ever struggles to overcome it. Water is a tranquillising, heat a disturbing agent.

Rocks are formed both by aqueous and igneous agency in the present economy of nature, and the products of these agents are in general easily distinguishable. The deposits from water are composed of limestone, which is sometimes a chemical product, sometimes a mechanical or sedimentary deposit, or of sandstone and clay, which are always of sedimentary origin. The accumulations formed in the beds of lakes, at the mouths of rivers, and in gulfs of the sea, are so stratified and composed of such materials. Moreover, these modern strata enclose remains of terrestrial, freshwater, or marine organic bodies, according as these existed in, or were transported into, the water; and they are deposited in the strata according to the periods when these were formed. In every respect, then, the modern aqueous deposits are exactly similar to the stratified rocks produced in former conditions of the globe. Whether they are equally extensive is another question; but it is clear that processes of the same kind have occasioned all these phenomena.

On this determination of the aqueous origin of stratified rocks enclosing organic exuviæ of aquatic animals, rests the doctrine of the relative antiquity of the rocks, according to their relative place in the scale of stratification. In the same manner as we cannot doubt that the lowest layer of the sediment from a pond, lake, river, flood, or inundation of the sea, is the most ancient, and the upper layer is the least ancient of all those which exist together, so in the series of stratified rocks, which were likewise deposited from water, the lower are the older, and the upper are the newer. It is not here a question of what periods of time elapsed between the deposition of the oldest and the newest; the general principle only is required to be granted, and it will be left to future investigation to draw the proper inferences on the lapse of time during the accumulation of the strata.

There can also be no reasonable doubt on another important topic. As at the present day (except under special circumstances), so in ancient times, we may be sure that the marine stratified deposits would assume the character of level, or nearly level surfaces, because this is the result of the ordinary action of agitated water. In whatever positions these strata are now found, we may always agree that they were at first deposited nearly level.

The rocky accumulations from modern igneous agency are exhibited to us in volcanic regions, where we see that the lava thrown out does not form true strata, except for very limited areas, though, in consequence of successive eruptions, it may be laid in many consecutive stream-like deposits. Even the scoria which is ejected from the volcanic cone, and falls more or less on all sides of it, is accumulated in such a way amongst the streams of lava, and with such a relation to the slopes of the ground, that it does not form true strata. The lava frequently forms dykes and veins.

The materials of these eruptions are not limestone, or sand, or clay, but consist chiefly of a variety of crystallised minerals, in which the bases of these rocks are united with other earthy, alkaline, and metallic substances. Finally, it is only by peculiar accidental circumstances that any remains of animals or plants occur in them. When the melted lavas come in contact with previously solidified rocks, some changes occasionally happen, which may be imitated by artificial heat. In all these particulars the modern products of fire resemble the ancient unstratified rocks. We may further remark, that the most abundant and characteristic mineral substances now obtained from volcanic rocks are equally abundant and characteristic of their older prototypes; that in

both classes these minerals are often found grouped together in the same manner; that some of the most abundant of the older unstratified rocks are not distinguishable from certain modern volcanic rocks; and that there is such a general resemblance between the two classes, and so much analogy of combination and appearance continually observable between them, that we cannot hesitate to pronounce the unstratified rocks generally to be the product of heat. It would not be right to say they were ancient volcanic rocks, for volcanos are only a particular case of the general effect of subterranean heat; and there are various facts connected with the history of the older rocks which do not often permit us to assign to them a real volcanic origin. On the contrary, certain differences, almost always existing between these and volcanic rocks, appear sufficiently marked to lead us to a theory of their origin, which may explain at once their general dependence on subterranean heat, and their particular differences from volcanic products.

There are some rocks which appear both stratified and crystallised, as certain limestones; others which are neither stratified nor apparently crystallised, as wacké and some sorts of claystone. Yet even these, and some other cases, which on a first view appear to confuse the classification and disturb the inference, are capable of satisfactory

solution. It is known by direct experiments that artificial heat is capable, under particular circumstances, of changing sedimentary limestones into crystalline limestone. Thus, Sir J. Hall actually converted chalk into granular limestone. Now the granular or crystalline limestone, above alluded to, sometimes occurs in such a relation to rocks of igneous origin that its crystalline structure is with much probability referred to the local development of heated rocks in that situation. In other instances we may easily imagine the interior heat to have produced the same phenomenon, though no igneous rocks be actually exhibited in the neighbourhood.

With respect to uncrystallised rocks which are also unstratified, we may remark that though, among the modern effects of volcanic fire, we have selected crystallised rocks as characteristic of these effects, and have noticed the analogy in this particular of the old unstratified and modern igneous rocks, yet neither in one class nor the other is it meant to be understood that such rocks are the only ones that exist. Here, again, we are aided by actual experiment. Mr. G. Watt has shown that the very same mass of chemical substance, perfectly fused and allowed to cool, will become glassy, earthy, or crystallised, according to the rate of its cooling. The same thing happens in volcanic products; the same thing, hardly

in a less degree, did happen amongst the ancient igneous rocks. We have, therefore, the means of explaining all the apparent exceptions to the general rules given above, and by a careful study of the cases shall probably in time arrive at a clear understanding of the conditions which occasioned all the phenomena.

STRUCTURE OF ROCKS.

It has been already remarked that the most important distinction in the structure of rocks is that of their being stratified or unstratified. The fundamental idea of a stratum of rock is that of a widely extended mass of matter, which settled to rest, while in an incoherent state, under the influence of gravitation, with or without any lateral impulse. According to this view we may imagine strata to have been formed by the falling or drifting of sand in the air; by the deposition of particles in a calm or agitated liquid; and by the solidification of a fluid mass.

Let us examine these cases in succession. The ashes thrown up from a volcanic crater fall around it, and collect in concentric laminæ sloping on all sides from the centre. (See Pl. II. fig. 9.) This may be called conical lamination: it is, in general, easily distinguishable from a case of conically uplifted stratified rocks, by the irregularity and discontinuity of the layers.

Sand, drifted by the wind, collects into particular forms, according to the nature of the obstacles to its progress. It is heaped against the old temples of Egypt; accumulated into irregular hills on the sea-coast, round the roots and stems of *Elymus arenarius* and *Arundo arenaria;* but on the wide plains of Western Norfolk, and on a greater scale in the African deserts, it is scattered in a more equable manner. Where a river impedes its progress the sand often fills up the stream on one side with a shallow projection, and causes it to excavate the opposite bank. Similar phenomena happen on the sea-side. No true strata are formed by such irregular and accidental causes.

Particles minutely disseminated in a quiet liquid, whether by chemical decomposition or mechanical disturbance, produce, when they fall therein, strata proportioned in thickness to the quantity of matter suspended above; that is, generally, proportioned to the depth of the water. Hence, in the freshwater lakes of Central France, it has been observed that the calcareous strata grow thinner toward the edges of the basins. The same happens to the very fine clays which, under the name of warp, are deposited on the low lands adjacent to the tide-rivers of the North of England.

But the matter which falls from an agitated

liquid partakes, in its arrangement, of the lateral influence of the currents and eddies. From the stormy waters of the Arve falls abundance of sediment, full of oblique and crossing laminæ which indicate the variable direction of the currents. The same structure is often noticed in sandstone strata, as in the cliffs under Nottingham Castle and Knaresborough Castle. For such cases the term oblique lamination is conveniently employed. (Pl. IV. fig. 12. *l.*)

A different result happens when a rapid stream delivers coarse detritus into a deep and quiet lake; the Rhone, for example, falling into the Lake of Geneva, communicates to the sediment a horizontal force, which, combined with the influence of gravitation, causes the particles to describe curves in the calm water. Parallel to these curves, which deviate more and more from the horizontal as the particles descend lower, the matter accumulates round the point where the river enters, and thus a peculiar concentric lamination is occasioned. In the deeper parts of the water the curves of descent are too steep for the matter to lie at rest, and consequently the laminæ are found to follow nearly conical slopes. (Pl. IV. fig. 11.) (See Mr. Yates's paper on this subject, Edin. Phil. Journal, 1831.)

It is evident that the most extensive and uniform strata are produced from a corresponding

diffusion in water of substances which slowly and equally settle on its bed. The regularity of the strata of limestone, shale, and coal is very remarkable; the irregularity and discontinuity of coarse conglomerates are no less striking: both these results are in conformity with effects daily produced on a smaller scale. The ocean is to be viewed as an unquiet lake, receiving sediments of various kinds under different conditions. The restless agitation of its surface-waters tends to diffuse far and wide the lighter matter contributed by rivers, or obtained by its own warfare with the coasts, while the coarser and heavier matter remains near the shore, and thus the materials are sorted, and transported to various distances, till they quietly settle in extended strata, which tend more and more to become horizontal, the further from shore and the more tardy the deposition.

In this way, we may see the means of distinguishing the truly oceanic from the truly littoral portions of old stratified formations: the former may in general be known by the regular and continuous stratification of the limestones and shales; the latter by the irregular mixture of local conglomerates, coarse shales, and debased and attenuated limestones.

The last cause of stratiform accumulation, viz. the solidification of a fluid mass, is exemplified in

modern lava, and in old plutonic rocks of several kinds. Modern lava has generally been consolidated in air, but the older igneous products most frequently under the pressure of water or a great thickness of incumbent rocks. The form assumed by lava, which has flowed and been indurated in the air, depends almost wholly on the shape of the ground. Round a volcanic cone the basaltic lavas are in the form of narrow irregular streams, directed down the slope, and thickest toward their base: in the valleys of Iceland, almost lakes of liquid rock have congealed, with all possible irregularity, owing to the cooling of the surface before the flowing of the under current ceased. Even when successive lava-streams have been laid one on another, hardly the least character of stratification is produced.

Some of the older plutonic rocks, which were poured out on the bed of the sea, have, indeed, on one surface a stratiform aspect, because they take the shape of the stratified rock beneath them; but their upper surface has those irregular bosses and protuberances which must inevitably result from the cooling of a partially fluid mass. Igneous rocks, which have been forced between strata of other materials, assume a tabular form, which might mislead a beginner uninstructed in the history of such irruptions. Many such *inter-*

posed beds, as they are termed, occur in the Island of Arran.

Besides the stratified structure, which is coeval with the deposition of certain rocks, there is another pervading *all* rocks, which has met with less attention than it deserves. All rocks are traversed by certain divisional surfaces, commonly called *joints*, which in basalt occasion vertical prisms, in clay-slate parallel tables, in shale rhomboidal faces, in limestone cuboidal blocks. There are many kinds of joints:—

Cracks (Pl. IV. fig. 12. *c*.), which in general do not pass through even one bed of stone. Some of these minute internal fissures are empty, others filled with carbonate of lime or small veins of metallic substances; some have their surfaces marked with a beautiful radiated crystallisation of oxide of iron or manganese, like delicate plants. These are often called *dry cracks* by the workmen. All these substances have, no doubt, been transferred through the pores of the rocks by electrical or other subtle agency; that they are not contemporaneous with the rocks is proved by the fact that, whether empty, sparry, or metalliferous, the cracks sometimes pass through shells, fishes, plants, and even divide the pebbles of conglomerate rocks. In the Rhigi; at Oban; at Kirby Lonsdale. (See Pl. IV. fig. 12. *p*.)

Joints go through a whole bed, or several beds of the same description. (Pl. iv. fig. 12. *j*.)

Fissures pass through a great variety of strata, though of a different nature, as sandstone, limestone, shale, and coal. They even divide strata belonging to different formations. They are either empty, partially lined, or entirely filled with crystals of carbonate of lime, metallic oxides, &c. (Pl. IV. fig. 12. *f*.)

There is amongst the great fissures in a given district of stratified rocks a remarkable parallelism, and a tendency to particular directions, which, at least in some instances, coincide with the lines of convulsion. The minor joints seem to be characteristic of the different sorts of rocks by their relative number, closeness, parallelism, and angles of intersection. In slate rocks the joints and fissures intersect one another with almost geometrical regularity; they are very symmetrically arranged in laminated shales; but in thick sandstones only the great fissures hold any regular course.

In unstratified rocks the joints have been little attended to, except when they appeared to produce a prismatic arrangement, analogous to that of basalt.

The production of joints in rocks may be referred to the condensation of their mass from an aqueous or igneous expansion; but the symmetry

of their arrangement can only be referred to some kind of crystalline action; and the parallelism of the great joints over large tracts of country seems the effect either of electrical currents controlling that action, or of peculiar, perhaps undulatory, movements affecting large parts of the crust of the globe.

POSITION OF ROCKS.

It is sufficiently evident that the rocks of aqueous origin were deposited in nearly horizontal strata, and the pyrogenous rocks mostly raised from below, and placed in various circumstances of contact with the former. The actual position of stratified deposits, with reference to horizontal surfaces, to one another, and to the masses of pyrogenous rocks, constitutes an important element in descriptive geology. Over very large portions of the globe the strata are still nearly horizontal: the deviation of their surfaces from the spherical surface of the globe, or the horizon of the place of observation, is called the dip or declination of the strata. Measured by the clinometer the dip is often found less considerable than it appears to unpractised eyes. A descent of $2\frac{1}{2}°$ for a large tract of secondary rocks is always thought remarkable. Scarcely any road, however dangerous from its steepness, slopes more than 10° to 15° from the horizon; mountain sides are abrupt if

they decline 18° or 20° (Carrock Fell in Cumberland), and covered with loose detritus, as the western front of Ingleborough, if they slope 45°. Very few precipices exist in the interior of Great Britain over which, as at Whitestone Cliff in Yorkshire, the plummet line may swing freely by the side of 100 feet of solid rock.

A line drawn on the surface of the strata at right angles to the dip is of course horizontal, and is called the "strike" of the beds. The strike and the terminal edge, or "outcrop," of the strata are generally on a great scale; but if the dip is very gentle, and the country much varied in elevation, the difference between them may be very considerable. The direction of the strike is always dependent on the situation o the points or lines which are the centres or axes of subterranean movement, and from or towards which the strata decline.

If there be a conical elevation of strata (as nearly happens in the valley of Woolhope, Herefordshire), the dip is quaquaversal, or radiates in all directions from the centre, and the lines of strike are concentric: if the axis of elevation be a straight line (as the range of the Malverns, the escarpment of Cross Fell, &c.) the lines of strike are parallel to it: between these extremes are found many gradations constituting elliptical

elevations (as Greenhow Hill, &c., in Yorkshire).

The strata are sometimes continuous over the axis, and sometimes wholly or partially removed, constituting what has been called a Valley of Elevation (as at High Clere in Hampshire). An anticlinal axis is such that the strata decline *from it* on both sides (as the Snowdonian Chain) see Pl. II. fig. 5.; a synclinal axis is such that the strata dip *toward it* on both sides. Some of the great lines of subterranean movements in England and Wales range ten, fifty, or a hundred miles.

In some cases the axis of subterranean movements is a *fault*, or complete fracture and displacement of the whole series of strata (Pl. II. fig. 6.) along a vertical or inclined plane, the beds being relatively depressed on one side, and elevated on the other. The extent of displacement, or vertical measure, in inches, feet, or yards, of the difference of level of the same strata of the opposite sides of the fault, is often called the *throw*, *shift*, or *cast* of the fault; and the "throw" is said to be *up* or *down* according to the side which is taken as the standard of comparison: it is often impossible to say on which side of the fault the strata were really displaced. If, as frequently happens, the fault is not vertical, its inclination (the angle *a s v*, Pl. IV. fig. 13.) is called "hade" or "underlay," terms applied to mineral veins;

its declination from the horizon being the angle *a s h*.

By the sides of faults, the strata are often slightly or considerably bent, sometimes in the direction tending to unite their disrupted parts, as *a*; sometimes in the contrary way, as *b* (fig. 13). In the former case they are said to "rise to an upthrow and dip to a downthrow," in the latter they "rise to a downthrow and dip to an upthrow." These are circumstances of greater importance than the slight attention paid to them by geologists might seem to indicate. They conduct us by an easy transition to the cases where the violence of the disturbing agency has been sufficient to render the strata for great distances directly vertical, so that they "stand on end," as in the Isle of Wight, and the escarpment of the Penine Chain, or even bend backward, as in the Malvern Hills. To the same violent agency operating on yielding materials we must ascribe the singular *contortions* of strata which occur in the limestones and shales of Yorkshire and Berwickshire, and on a far grander scale in the limestones of Altorf, Lauterbrun, Wallenstadt, and the Valley of the Arve. (See Pl. IV. fig. 14.)

In a certain sense all these phenomena of unusual position of stratified rocks are geological accidents; yet they are not without their laws, and some of these are partially known. Faults,

for example, are most frequently found to dip or decline under that portion of the divided strata which is relatively depressed, as *a* and *b* in Pl. IV. fig. 13., not as *x* of the same figure.

Contorted strata happen most frequently along the sides of elevated chains of mountains, where great lateral pressure may be supposed to have acted (Pl. II. fig. 6. *c.*), and in soft or thinly laminated rocks which might yield in undulations, not snap in fissures.

Axes of disruption and elevation are usually accompanied by cross rents or faults, and sometimes by parallel faults, producing two sets or systems of fractures in the crust of the globe, more or less rectangular to each other. The philosophical study of these and other laws of phenomena of unusual position of strata in relation to the structure of the rocks and the forces concerned in displacing them, one of the most attractive in modern geology, has been well opened by Mr. Hopkins's Memoir on Physical Geology in the Cambridge Phil. Trans. See also Illustrations of Geology of Yorkshire, Part II.

As convulsive movements happened in the crust of the globe at various epochs after the accumulation of some strata and before the deposition of others (see Pl. II. fig. 7.), it is frequently found that the older dislocated strata are covered over by the undisturbed newer deposits (Pl. IV.

fig. 15.); and when this is not the case, some great difference of dip, either in amount or direction, as seen in neighbouring natural sections, or some great difference of strike and outcrop, as traced on the surface, will at once reveal to the careful observer the geological epoch of the convulsion. To all such cases of discordant position of adjacent strata the term "unconformity" is usefully applied; it always marks the occurrence of subterranean movements, and changes of level, in the period between the ages of the newest dislocated and the oldest undisturbed strata, their ages being in fact the limits of error of the problem. Thus in some cases the geological date of the disturbance is accurately, in others approximately fixed.

Bearing in mind the conclusion adopted as to the relation of the lines and centres of subterranean disturbance to the eruption of pyrogenous rocks, the student must complete his researches as to the position of strata in any given district by determining the situation and phenomena of the nearest erupted masses of pyrogenous rock. If igneous rocks appear along a great axis of elevation, as in the S. E. of Ireland, the Lammermuir, Cumberland, Malvern, &c.; on the flanks of a mountain group, as in Westmoreland; or in minor anticlinal lines, as the Breiddyn Hills, the Wrekin, &c., their nature, the chemical and me-

chanical changes produced when they come into contact with the stratified masses, alterations of composition, texture, structure, hardness, occurrence of spathose and mineral veins, minute contortions and fractures of beds, and other phenomena, must be accurately noticed. Along and near to great lines of disturbance, basaltic, porphyritic, and other *dykes* frequently occur, and sometimes are accompanied by remarkable alterations of the neighbouring rocks (Isle of Arran, banks of the Menai, Teesdale, &c.): but one of the greatest lines of subterranean movement in Great Britain, the Tynedale, Penine, and Craven Fault, is only partially marked by the occurrence of such rocks in or near its long and flexuous course, and the great upturning of the chalk and tertiaries in the Isle of Wight is without any superficial indication of igneous agency.

PHYSICAL GEOGRAPHY.

Having thus arrived at a clear view of the origin and relative position of the rocks composing the crust of the globe, we must turn our attention to the surface, which, as before observed, is formed upon the edges and planes of these rocks (fig. 2.), and inquire what connexion there may be between the physical features of the surface of the globe and the subjacent rocks. Taking the most general view which the subject admits, we

may consider the mountainous regions of the globe as rising in the midst of the broad plains and gently undulated regions, like islands in the sea. Some particular plains are surrounded and defined by the chains of elevated ground, as the Plain of Bohemia; but it is a more general fact that the plains spread round and inclose the mountain masses. The depths of the sea appear to balance the ridges on the land. There are in the sea certain lines and certain centres of depression, as on the land are particular chains and peaks of elevation. If we could remove the whole of the enveloping ocean, it is probable that the greatest depths of the basins of the ocean would be found proportioned to the greatest elevations of the land, and equally limited in area. The far greater part of the ocean is of a moderate depth, as the far greater part of the land is of a moderate altitude.

Putting out of consideration, for the present, the loose water-moved fragments which cover to a small depth in many parts the actual solid framework of the earth (fig. 2.), we may state as a general truth, that the great plains and moderately undulated regions of the dry land owe their principal features to the quiet deposition of the stratified rocks below them; while the mountainous lands, on the contrary, owe their peculiar features to the elevation of pyrogenous rocks along their

chains or amidst their groups and peaks. It is a general law, confirmed by most ample evidence, that the interior parts of mountainous regions consist of granite and other pyrogenous rocks rising from below all the strata, and bearing them up to their present elevations. From these elevated points and lines, both the subjacent igneous and the superior stratified rocks descend at various angles towards the plains and more level regions, beneath which they sink and pass for various distances, until they again emerge in some other mountain group having similar characters. In consequence of this arrangement, it happens generally that the oldest strata, those which sink deepest under the plains, rise highest against the mountain slopes; a circumstance easily understood, though sometimes called *a geological paradox* (fig. 5.). The most constant of all the facts connected with this part of the subject is the development of granitic or some other pyrogenous rocks about the centres of the elevated groups, from beneath all the strata there occurring. Very frequently cracks and fissures of the strata are filled by these igneous rocks injected from below, and thus in some cases the proximity of their masses is indicated when they cannot be actually seen.

The surface of the earth derives all its diversity of form and products from the originally different

nature of its constituent rocks, the variety of positions into which these have been thrown, and the consequent inequality of effect produced upon them by atmospheric and other modifying agencies. Had the stratified rocks remained in their original nearly level position, all the immense variety of mineral treasures which they contain would have been hidden from the eye of man, and the dry land would have been a monotonous waste, without that picturesque grouping of mountains, that pleasing variety of hill and valley, that ornament of bay and promontory, which we now gladly acknowledge to be a great source of enjoyment and instruction.

And, as we behold how marvellously the animal and vegetable creations are adapted to each other, and both to the local influences of climate, soil, elevation, proximity to the ocean, and other important conditions, produced by geological revolutions, there is no room for doubt that the subterranean movements by which this fundamental diversity of the earth's surface was occasioned, are as much a part of the general plan of creation as the existence of the atmosphere, the proportion of land and sea, or the succession of the seasons.

The sea-coast of every country derives its characteristic outlines, its rocky cliffs and alluvial depressions, from the unequal hardness, various direction, and degree of elevation of the rocks. The

long horns of Cornwall and Caernarvonshire coincide with axes of convulsion; Pembrokeshire, like the Isle of Wight, is extended by the operation of similar causes from east to west; Flamborough Head, composed of chalk, projects into a magnificent promontory, round which the currents of the German Ocean turn, with fatal perseverance, to waste the clays and sands of Holderness.

The chains of mountains and ranges of hills, and the vales and plains which surround and divide them, are all occasioned by similar causes. The range of Snowdon is the line of an axis of elevation; the Penine Chain, from Ingleborough to the South Tyne, is formed by a magnificent dislocation, which depresses the strata on the west above 1000 yards; and where this dislocation turns to the east along the Tyne, and to the east and south-east through Craven, it produces, in the midst of a mountain country, two great irregular valleys across the summit of drainage.

The forms of the individual hills and valleys are occasioned principally by peculiarities in their geological structure. Compare, for instance, the pinnacled primary rocks of the high Alps with the broad swellings of the oolitic Jura; the fantastic cappings of basalt in Scotland with the serrated slate mountains of Cumbria and the green swelling outlines of the English chalk.

How different are the vertical cliffs of mountain limestone, which have been rent asunder in Mendip and the Peak, from those of other rocks! The streams which foam through many channels among the slate rocks of Lowdore, or rush in white lines down the slopes of Skiddaw, give a totally different effect to the scenery of the Cumbrian glens from that which belongs to the lofty cascade of Hardrow, and other less-known waterfalls, across the ridges of limestone in the magnificent dales of the North of England.

A general acquaintance with geological truths is therefore absolutely indispensable to an enlarged intellect, which is desirous of forming right general views of the arrangements of existing nature, and especially of physical geography.

GENERAL VIEW OF THE STRUCTURE OF THE EARTH.

Leaving the question of the original aggregation and interior arrangement of the matter of the globe to the astronomer, and the laws of the atomic constitution of its mass to the philosophical chemist and crystallographer, we may gather from the preceding statements sufficient grounds for a general view of the structure of the exterior crust or shell of the globe. By far the greater portion of the surface of the earth is occupied by rocks which were deposited by water in the form

of strata, more or less approaching to a horizontal position, which succeed one another in a certain order of superposition, are of different antiquity according to this order, and are continuous for less or greater distances. In these strata multitudes of remains of plants and animals lie buried, which are for the most part distinct from the plants and animals of the present day, though belonging to the same great divisions, and formed upon the same general plan of terrestrial and aquatic life. This system of stratified rocks extends to a variable depth, not exceeding a few miles, and below it and amongst it occur various rocks, which are not stratified, and do not contain organic remains, but consist of such minerals, and occur in such circumstances, as to be clearly the result of igneous agency. These pyrogenous rocks are frequently found piercing through the strata in various ways, as if uplifted from below. In some cases, also, the effects of heat are traceable in the stratified rocks themselves, in consequence of which they have partially or generally assumed some of the appearances properly characteristic of the pyrogenous rocks.

The dry surface of the earth is formed on the edges and surfaces of the strata and tops of the uplifted pyrogenous rocks, in such a manner that while the great plains and moderately undulated regions consist almost entirely of stratified rocks,

the mountainous parts usually contain an axis or nucleus of pyrogenous rocks covered by stratified rocks; both of which groups decline on all hands from the mountain chains, sink below the more level regions to various depths, and pass to various distances.

Both fire and water have been actively engaged in the construction of the earth. Water has deposited from above, in a settled order of succession, at successive times, many extensive strata and sets of strata, variously filled with the remains of plants and animals which existed during the several periods; and heat has expanded these strata from below, and thrown up a different set of rocks from the deeper parts of the earth. It is the business of the geologist to trace with accuracy the effects of these agencies, separate and combined; to arrange these effects in a chronological order, and thus to compose a correct if not complete history of the revolutions by which the earth has been brought to its present condition, stored with its present wonderful variety of animal, vegetable, and mineral forms, and made fit for the residence of a being gifted with that human curiosity which prompts him to examine, and that divine reason which enables him to interpret, the works of nature, and through them to hold a sublime communion with the Creator of the universe.

PART II.

THEORETICAL VIEWS AND RESEARCHES.

SUBAQUEOUS PRODUCTION OF THE DRY LAND.

THE most important of all the leading truths established by modern geologists was not wholly unperceived by the enlightened philosophers of antiquity. When Ovid ascribes to Pythagoras the opinion that, in the course of the changes of nature, what is now dry land was formerly sea, and the contrary, and illustrates the doctrine by the submersion of cities along the shores of the Mediterranean, and by the occurrence of marine shells far from the sea, it is impossible not to be struck with the force and simplicity of the argument. Ideas of the same kind were distinctly announced by Strabo and others accustomed to the phenomena of earthquakes in Asia Minor. Even Herodotus was attentive to the sea shells on the hilly margin of the Egyptian valley.* But the poetical notion of alternations of land and sea

* Book ii. § 12.

over given regions, suggested by limited phenomena, is distinguishable from the philosophical conclusion, based on universal research, that the whole of the existing continents and islands have been reared out of the bosom of the sea,—that all our highest mountains are of comparatively modern date, and that in some former period of the world the ocean-currents flowed over the yet unborn Alps and Pyrenees, as well as over the plains of India, Africa, and America.

Whether, at the time when all our continents were beneath the sea, there were other continents raised above it, is a matter which it is difficult to bring fairly within the scope of inductive science, except in a very limited form, and upon rather doubtful assumptions. The only clear and *certain evidence* for the existence of land in other situations than where it now appears, is to be sought in the history of terrestrial organic exuviæ imbedded in the earth; the only reasonable *presumptive evidence* in favour of such a doctrine, must be founded on mechanical considerations connected with the mass and depth of the waters of the ocean. To conclude that because continents were raised in one quarter others *must* have been depressed elsewhere in a certain proportion, is unsafe, because it requires us to admit what is perhaps false, viz. that the spaces occupied by the solid and liquid parts of the mass of the globe

have always been exactly and invariably in the same proportion to each other as at present. Who can assure the truth, or even the probability of such a law?

The simple argument of Ovid,

> ——— Vidi factas ex æquore terras,
> Et procul a pelago conchæ jacuere marinæ,

will probably never lose its power of convincing mankind that they stand upon the elevated bed of the ancient sea. When we find shells and corals, which beyond all doubt must have lived in the sea, deposited in the interior of solid rocks, with all their delicate ornaments of structure uninjured; and, lying in these rocks as they usually do on the bed of the sea, we are compelled to conclude, not only that these exuviæ were deposited by the ocean, but that the animals actually lived in or near the very spots where their remains are buried, and were there quietly covered up by the deposits of earthy matter then in progress. Each of the stratified rocks inclosing these remains was really in succession the bed of the ancient sea; and wherever we find the faithful testimony of imbedded marine exuviæ, the conclusion is immediate and unobjectionable, that the ancient bed of the ocean is laid open before us. The extent to which this principle is applicable, varies in different countries. In Europe generally, in North

America, in India, a large portion of the whole area may thus be proved to have been formerly submerged.

Strata containing no organic remains sometimes alternate with others which do contain them, and they have evidently been subject to the same local conditions, and have had the same oceanic origin. Such strata as red sandstone, and many kinds of slate which, in England at least, contain no organic remains, were as certainly formed on the bed of the sea, as the conchiferous limestones above and below them. Moreover, strata which in some countries contain no organic remains, do contain them elsewhere, as, for instance, the red sandstone; and, by combining all these facts together, we arrive at the conclusion that the Ovidian argument, from the presence of marine exuviæ, applies to at least three-fourths of the whole area of the solid land, and to the whole series of strata except those which lie at the very bottom; and to all heights above the level of the sea, and to all attainable depths below it. But even if there were no marine exuviæ in the stratified rocks, yet, because of their composition, texture, and structure, their regular order of succession, and other characters, they speak for themselves, and show most clearly that they are not to be regarded in any other light than as deposits upon the bed of ancient waters. In this case we make

no exception, but include with equal confidence the most ancient primary slates and the most modern tertiary sands.

Thus we arrive at the conclusion, that not only all the great plains and all the undulated portions of the land were formerly submerged, but that the flanks and often the very summits of the loftiest mountains are composed of rocks formed under water; for all these are composed of stratified materials of some kind or other.

The same conclusion applies likewise to the pyrogenous rocks which appear about the centres of mountain groups; for, as we have before seen, these rocks appear in such a relation to the strata of the mountains, that, by a large induction of facts, we are led to conclude that they have been thrown up from beneath all these strata, and have, in fact, been upheaved with them from their original situation on the bed of the sea. Therefore it is concluded, as a fundamental maxim in geology, that the whole area now occupied by dry land was formerly covered by the sea. We may next inquire into the agencies by which the land was redeemed from the waves.

ELEVATION OF LAND.

The strata formed upon the bed of the sea could only be laid dry by one of two processes; either the general level of the sea has been

lowered, as Werner imagined, or there have been vertical movements of the solid parts of the earth. The notion of the gradual lowering of the level of the ocean is one of those imprudent suppositions which the constantly increasing connexion of geology with exact science has nearly banished from our systems. It was adopted with the view of accounting for the often observed fact, that the strata which descend to the greatest depth under the plains, and are certainly the oldest, are also found rising to the greatest height along the flanks of the mountains. The Wernerian hypothesis assumed that the great physical features of the globe, its mountains and plains, were aboriginal; it not only assumed that rocks were, for the most part, produced from water, but extended this assumption to basalt, porphyry, and granite, and took no steady view of the enormous fractures and foldings by which the whole crust of the earth has been disturbed; and it was to agree with these fundamental errors that the monstrous notion of the gradual and universal sinking of the water-level, from the summits of the mountains to the shores of the actual sea, was framed. This notion is so contrary to common sense, that it will be instantly rejected by every mind which is not prepared to admit an unlimited variation in the quantity of water upon the globe.

No direct collision with natural philosophy can

be chargeable upon the other supposition; we must therefore judge it by comparison with observed facts. The vertical movements may have been elevatory or depressing, or both: they may have been sudden and convulsive, or gradual. In every case of *convulsive* elevation or depression along a line or about a centre, the strata, originally deposited nearly level, must be placed in angular positions with respect to the horizon, and the dips or slopes thus occasioned will be most considerable along the line or about the centre of the disturbance. Thus, in the annexed diagram (fig. 10.), *d* represents a case of depression, and *e* of elevation. Nearly analogous results would follow a *gradual* vertical movement of the strata. If the elevatory or depressing action was exerted over a very broad area, and was gradual, it might happen that no sudden or violent dips should be anywhere traceable, but the effect would be a gradual intumescence or subsidence. These are obvious truths, and they are sufficient for the purpose of examining the question of the desiccation of the land.

It cannot be doubted that both depression and elevation have happened to many parts of the bed of the sea; but when we proceed to those parts of the country which were most affected by these disturbances, we are at once convinced that it is to local elevation of the bed of the sea we

must ascribe the existence of mountains. The general fact of the rapid dip of the strata in the proximity of the mountains (fig. 5.), contrasted with their gentle slopes or nearly horizontal position, even at moderate distances, is sufficient proof of this. As nothing can be more certain than the dependence of the figure of continents and islands upon the direction of the ranges of mountains, there is no room to doubt that all our solid land has been *raised* out of the sea, parallel to certain lines, and around certain centres of vertical movement.

The confusion of dip (fig. 6.) so commonly observed in the proximity of mountains, seems to indicate that the elevatory movements were sudden and convulsive; but the full discussion of this subject would lead to theoretical considerations unsuited for an elementary work. Whether depressions in other parts of the globe corresponded to the elevations in these, is a question of the same character.

We may, however, advance our conclusions, as to the elevation of land, one step further, by considering the relation of the lines and centres of elevation to the eruption of pyrogenous rocks. The appearance of these rocks along the lines of subterranean movement is so constant and characteristic a phenomenon, that we cannot doubt of the dependence of both upon the same local

causes. Some pressure from within, determined to particular points, has evidently upheaved the strata with the subjacent pyrogenous rocks. In some cases it is probable that the pyrogenous rocks were upheaved in a solid form; in others it is demonstrable that they were in a state of igneous fusion, so as to flow into cracks and fissures of the strata. The phenomena may be plausibly explained upon the supposition of the local production of great subterranean heat, or by considering the convulsive movement as a paroxysmal relief to a general pressure upon the internal fluid nucleus of the globe. Each of these views has able defenders.

Nothing is more evident in physical geography than that the extent and direction of the land depend on the ranges of mountains: these have been shown to owe their elevation to subterranean movements; and this is generally thought sufficient proof that the elevation of all the solid land is due to the convulsive rising of the mountains. This is, however, not proved, though we may always justly admit that large breadths of land rose with the mountains. But it is not adequate as a general explanation of the desiccation of the continents, for a very sufficient reason, viz. that many mountains were raised by the convulsions, of which they exhibit traces, *before the strata were formed, which are now laid dry around them.*

Persons who are aware of this difficulty propose another view. They say, as the mountains certainly owe their elevation to convulsions centred beneath them, so also probably were all the other parts of the dry surface of the earth raised by other convulsions, suitably posited. This is equally erroneous. There is no ground whatever for applying this hypothesis to the desiccation of the eastern and south-eastern parts of England, the north of Germany, and other large tracts of Europe; for in all these cases no convulsions can be traced at all adequate to the effect.

There remains for these cases, which relate to perhaps half the area of the dry land, only the hypothesis of *gradual elevation* of large tracts, either by the manifold repetition of small disturbing movements, or some general expansion beneath a whole physical region. Many of the Swedish naturalists believe that such an expansion is at this moment gently raising a great part of the Scandinavian peninsula. Lyell, from personal examination, has been led to adopt these views, which are also sanctioned by the authority of M. Arago; and illustrated by the well known historical case of the movements which have happened to the Temple of Serapis at Puzzuoli.*

* Babbage in Geol. Soc. Proceedings.

RELATIVE ANTIQUITY OF LAND.

One of the most interesting of the results to which a careful study of the circumstances of the elevation of mountains has conducted geologists, and at the same time one of the most certain, is the knowledge that *the dry land is not all of the same antiquity;* in other words, that some mountain ranges, and some large regions, were raised above the sea long before the occurrence of the convulsions which affected the level of other countries, and even before the production of the strata of those countries. For instance, we have no doubt that the Grampian, Lammermuir, and Cumberland mountains were dry land long before the Alps were reared from out of the sea, and while the greater part of the area of Europe was occupied by the ancient ocean.

How is this ascertained? It depends upon the determination of two leading truths: First, That the series of convulsions to which mountain ranges owe their origin, were effected at many different and relatively ascertainable periods. Secondly, That by these convulsions, or some gradual operation, the bed of the sea was not only *relatively* raised in certain parts, but particular portions of it uplifted above the level of the water.

The relative age of convulsions is known by

observing what strata *are* and what *are not* dislocated by them. If, for instance, as on the borders of Cumberland, the *old* slate and limestone strata are *dislocated* in certain directions, while, in the prolongation of these directions, the *newer* strata of red sandstone are *not disturbed*, but lie level over the sloping surfaces and edges of the others, we know that the convulsion happened after the formation of the slate and limestone, but before that of the red sandstone (fig. 7.). Again, because on many of the peaks and in many valleys of the Alps tertiary strata are found in a state of dislocation, it is clear that the last dislocations of the Alps were during or subsequent to the tertiary era. Always, the age of a convulsion is less than that of the dislocated strata, and greater than that of the strata which lie undisturbed, and unconformable on or against the former. (Pl. II. fig. 7.)

That certain parts of the bed of the sea were not only raised in relation to other parts, but absolutely reared above the waters into ranges of high ground, is known by the circumstance, that since the date of the convulsions which can be traced in them, marine strata have been formed around them, and in hollows of their surfaces, in such a way as to indicate that they stood up like islands, amidst the waters, defining the area over which the sea could form its deposits, and pro-

ducing the vegetables and other remains of terrestrial beings, which are imbedded in these deposits. Thus the Cumbrian group of mountains was dry land at the time of the deposit of the red sandstone around it; the same was the case with Charnwood Forest; and by continuing researches on the principle of combining the evidence of convulsive movements, and subsequent deposition of marine strata, we may hope to see light gradually break in upon the interesting problem of the ancient hydrography of the earth.

PERMANENCE OF THE LEVEL OF THE OCEAN.

It has already been shown that the whole of the dry land was formerly submerged. The preceding statements will probably be admitted as sufficient to prove the justness of the data for our conclusions, that the dry land is not all of equal antiquity, as the strata composing it certainly are not.

We have stated on what grounds geologists conclude that the desiccation of much of this land is a consequence of subterranean movements, and that for the remainder it is preferable to appeal to a more gradual and general change of relative level of land and sea. It has also been stated that the drying of the land by a general subsi-

dence of the ocean level is a mere delusion, and that the facts can only be explained by internal movements producing locally sudden or gradual change of dimension. Though the Wernerian hypothesis of the gradual subsidence of the ocean, which to suit the phenomenon which it professed to explain must have been to the extent of some miles, is now little regarded, it is necessary to show the line of argument according to which it is allowable for geologists to take for granted the permanence of the level of the ocean, *independently of astronomical vicissitudes.*

In this argument the quantity of water upon the globe is supposed to be constant: we have clearly no right to suppose otherwise. Variation of the level of the water may happen in consequence of internal movements and displacements of the parts of the earth, or from a change of the temperature of the globe. *Displacements* of the parts of the globe may cause land to sink or rise, or both. If any part of the bed of the sea sinks into a cavity, or rises so as to leave a cavity, the ocean level will be altered in proportion to the bulk of this cavity. The greater the cavity out of which any part rises, or into which any part sinks, the greater the change of level. If we suppose three fourths of the globe to be covered by water, and imagine a portion of the bed of the sea, equal in cubic content to the land now above

the water, to sink into a cavity, the dry land remaining unmoved, the depression of level occasioned over the whole ocean would be something more than one third of the mean height of the land. This we may take at 1000 feet: consequently the depression of the sea upon this enormous sinking would be something more than 333 feet. If the existing dry land should sink into a cavity, so that it should be just submerged, the level of the sea would remain nearly unaltered.

The converse is true. If the bed of the sea should be raised, but not to the surface, and leave below it an internal cavity, there will be a general elevation of the ocean level proportioned to the cavity; if any portion of the displaced mass of earth should project into dry land, the level of the ocean will be raised in proportion to the difference of cubic content between the cavity and that quantity of land which projects above the surface *directly*, and to the new area of the ocean *inversely*.

But if we discard the notion of cavities, and suppose the elevation of one part to be compensated by the depression of another, the ocean level will vary merely as the quantity of land above its surface. It will rise by the sinking of the land under it, and the contrary. If we suppose all the dry land to sink till it be submerged, it will cause the ocean to rise about 250 feet. To

such a depth then, and no more, could the ocean have sunk upon the rising of this mass of land. If at all times as much land rose above as sunk beneath the surface of the sea, the ocean would remain level.

The effect of a general *change of the temperature* of the globe in altering the relative level of land and water cannot be stated, unless we assume some fixed temperature for the water. In this case the change of dimension must go to some hundreds of miles on the radius before the relative level of land and water would be so affected as to account for the emersion of a large part of the land. A change in the mean temperature of the superficial parts of the globe is a probable geological cause of some fluctuation of the ocean level; but its effect cannot have been considerable.

Astronomical vicissitudes would for the most part be insensible in altering any of the dimensions of the globe: and unless we take into account a great displacement of the axis of rotation of the earth, we are forced to admit that the mean level of the ocean is nearly permanent, and that the dry land has been really *raised* out of its bosom by the force of subterranean movements. What was exactly the nature of these is a problem which must be intrusted to the researches of mathematicians guiding the industry of geologists.

MOVEMENTS IN THE CRUST OF THE GLOBE.

Perhaps the simplest case of these movements is that best known, in detail,—the case of mineral veins, trap dykes, and common faults. In each of these phenomena, the earth's crust, so far down as we know it, has been *broken* asunder: by attending to the *direction* of the fractures in a given large district, as Cornwall or Derbyshire, it is found that in certain directions more faults occur than in any others. Often two systems of veins thus appear in such a district — one, the "right running," passes from E. or E.N.E. to W. or W.N.W.; and another, the "cross courses," as their name implies, traverse the first-named veins N. or N.N.W. to S. or S.S.E. It is found in some well-examined cases, that these two sets are not of the same geological date, for one system is displaced by the other.

Now, these results are such as would arise if there had been below all the strata which are broken *a general pressure*, such as steam or expanding liquid, producing a strain *across the whole district*, which is occupied by one of the systems of fault.* The general idea of internal pressure, to

* Hopkins's Researches in Physical Geology, Camb. Phil. Trans. 1837.

which we are thus conducted, is strengthened by reference to another form of displacement of the strata, that of the anticlinal axis, a phenomenon observable in almost every mountain chain, and often extending much beyond them. Along or near to these lines of fracture igneous rocks are not unfrequent. Parallel to a main anticlinal axis, as, for example, that of the Highlands, running north-east and south-west, and that of North Wales, which takes a parallel direction, we often find other anticlinals and synclinals, which preserve, on the whole, parallel courses. They appear to be all of the same geological age, and thus widen still more the inferences that some very extensive subterranean force has been concerned in the effect.

But it is to M. De Beaumont that we are indebted for an idea of this force still more general: he has concluded, from many observations, that there is some real dependence between the geological age of disruptions and their direction — those of one particular epoch being parallel, or nearly so, to the same great circle of the sphere, even in very distant localities. If this could be sufficiently established, there would be no doubt of the effect being due to an almost universal internal disturbance, such as might be compatible with the supposition of the earth being internally fluid by heat at the epoch of these disloca-

tions. There are certain phenomena connected with these numerous anticlinal and synclinal folds, which allow of no other supposition than that in the regions where they occur — as in Wales — the strata so bent and folded, occupy an arc of the earth's surface less by much than their own length. In the case of many faults, the contrary effect happens; the broken strata, by their means, are made to spread over an arc greater than the length they occupied before fracture. Each of these cases is consistent with the supposition that formerly the earth's crust floated on an interior molten sea; and the phenomena of volcanos teach us that at least partially it is so now in certain districts. We may, therefore, consistently ask, is the earth still generally fluid within?

INTERNAL FLUIDITY OF THE GLOBE.

Happily for geology, it is not left in this dark research to its own feeble light. The theory of gravitation here comes to its aid; and, by a careful analysis of one of the most remarkable among the phenomena which characterise the earth's orbital motion, shows, if not the exact truth, the limits within which the truth lies. The phenomenon alluded to — the "Precession of the Equinox" — is caused by the attraction of the sun and

moon upon the protuberant matter in the equatorial regions of the earth. Were the earth a perfect globe, with a symmetrical internal structure, its axis would not describe in the course of ages a large circle in the heavens, nor would the return of the seasons be marked in successive years by continual variation of the equinoctial points among the stars. It is by comparing the perfectly known measure of the precession with what *would have been* the measure if the earth were wholly fluid or wholly solid within, and if its density were uniform, or varied in certain ways, that it has been found possible to solve, approximately, this great and important problem. Mr. Hopkins, to whom we are indebted for this and other gifts to geology, concludes, from the whole investigation, that the earth cannot now be *wholly fluid* within until we descend below the surface about 1000 miles; but it appears not improbable that it may be *partially* so at less depths, provided the fluid spaces were insulated, or had only slight communication.

On this subject we must refer to the laborious memoirs of this accomplished mechanician, in the Phil. Trans., 1839–40–42; and shall only add, that he is engaged in completing the investigation, by experiments on the effect produced by *pressure* on the temperature of fusion — an effect obviously

of the utmost importance in questions regarding the internal fluidity of the globe.

TEMPERATURE OF THE GLOBE AT SMALL DEPTHS.

But whatever may be the final result of these inquiries into the *fluidity* or solidity of the interior of the globe, it is certainly *hot* within. We do not appeal for proof of this to volcanic phenomena, because these, extensive as they are, may be conceived to be locally excited by chemical actions. It is by experiments conducted in regions far from volcanic excitement, that the data of most value have been obtained. In mines and collieries the warmth continually augments as we pass lower and lower from the surface; and this increase of heat follows at each place with much regularity a certain rate, seldom varying much from the general proportion of one degree of Fahrenheit for every fifteen or twenty yards. At this rate, the heat of boiling water would be attained under London at a depth of 2400 or 2800 yards. The same conclusion arises from the "Artesian" experiments, by which water is procured from considerable depths. In the case of the well of La Grenelle, at Paris, a depth of 1791 feet gave an increase of temperature of thirty degrees; and the salt spring of Kissingen, rising

from a depth of nearly 2000 feet, was found to give nearly the same result.

The great heat which is thus indicated in the deeper parts of the earth no doubt communicates gradually and slowly a certain warmth to the surface. This effect is not at present sufficient to affect in a sensible degree the temperature of the surface. But in earlier periods, when the thickness of slowly conducting rocks over the source of heat was less, the warmth communicated to the land and sea may have been greater.

The temperature of the earth's surface at present is mainly dependent on heat imparted from the sun, and cold caused by radiation into the clear planetary spaces. The balance of these contrary actions, modified by the atmospheric peculiarities of surface, gives the surface temperature. It is dependent on latitude; but not less so on the form and distribution of land and water, currents in the sea and in the air, height of ground, and other causes.

At any one place on the earth's surface the mean temperature of the year is nearly the same as that at small depths from the surface; but the propagation of heat and cold is so slow through the rocks, that while the greatest heat of summer is felt at the surface about the middle of July, it does not penetrate to the depth of 6 feet before the latter part of August, reaches 12 feet in the

beginning of October, and 24 feet about the middle of December, thus reversing at that depth the summer and winter.

The *range* of temperature diminishes rapidly as we descend below the surface. At the surface between the summer and winter, we have about 30°, in the central parts of England, and at a depth of about 70 feet, this range is reduced to less than $\frac{1}{1000}$ part, and is practically insensible. The mean temperature, in our latitudes, and amidst all fluctuations, is found to augment as we go downward; after reaching the depth of 70 feet, (more or less according to the nature of the rock) this augmentation is steady and constant, because it depends only on the *permanent or slowly changing heat of the interior.*

CHANGES OF CLIMATE.

There is reason to believe that during the long periods expended in the production of the whole great series of stratified rocks, and in the elevation of these out of the sea, the local temperature and other circumstances which influence the growth of plants and animals, both on the land and in the sea, were subject to remarkable changes. In this branch of the subject, the progress made of late years in philosophical botany and zoology is found of great importance. Without some fixed

notions of the dependence of organic forms upon the influence of temperature, moisture, and other conditions, — without some clear proofs of the geographical limitation of the existence of species in a natural state, according to definable circumstances, it would be impossible to come to any conclusion respecting ancient climate. Besides this, it is necessary for a good argument on this subject that the fossil organic remains on which we found it should be very carefully compared with existing tribes, and their several degrees of analogy or difference noted. It is evident that any conclusions as to the character of ancient climate drawn from comparison of fossil plants and animals with those which now inhabit particular regions of the earth, will be more or less binding as the analogies obtained are more or less exact and numerous.

In the existing system of nature the forms of life become more numerous toward the equator, and vanish altogether toward either pole. Thus, Humboldt counts only 4000 species of plants in temperate America, and 13,000 in tropical America; 1500 in temperate Asia, and 4500 in equinoctial Asia. In some natural groups of plants, as, for instance, Ferns, the species grow to the greatest magnitude in warm regions, and dwindle to the smallest size in colder countries. These instances serve to point out the principle of the

investigation of dependence of organic life upon temperature. The results obtained by this process apply accurately to the sea *at small depths,* and to the land *at small elevations.* In the gulfs of the ocean, and on elevated mountains, variations of temperature obtain, which require to be allowed for. Thus, in mountainous regions, the mean temperature of the air diminishes at the rate of about 1° Fahr. for 100 yards' elevation; and the flora of the mountain-slopes varies in a corresponding manner, so that the plants collected from the base of the Alps, differ in a nearly constant manner from those at moderate heights. At the greatest height, where the cold is severe, the plants resemble those which in more northern regions flourish near the level of the sea.

The relation of bulk and temperature in water is of a remarkable kind. At a temperature a little below 40° Fahr., fresh water is in the highest state of condensation (under the ordinary pressure of the atmosphere); and therefore in all cases when the temperature of the surface of fresh water sinks to below 40° Fahr., the particles so cooled descend from the surface toward the bottom. If this process be continued till *all the mass of water* is reduced to below 40° Fahr., the surface may begin to freeze, which is the case with most freshwater lakes; but owing to the depth of others they never freeze. The case is different

with salt water, which continually grows more heavy as it is cooled, even to the freezing-point, which is several degrees below that of fresh water. The sea may be looked upon as a great lake, which never freezes except in latitudes where the cold is so extreme as to overcome the downward tendency of the cooled surface-water, and convert it into ice, which, being specifically lighter, floats on the surface. In all latitudes the hottest sea water remains at the surface, or tends to rise thereto.

The greatest difference of temperature in the ocean, according to latitude, exists at the surface; the least difference in the deeper parts. We must therefore direct our inquiries, as to the influence of marine temperature upon organic life, to those plants and animals which constantly dwell near the surface of the water.

The play of oceanic currents materially diminishes the extremes of even its surface temperature, so that the polar ocean is warmer, and the equatorial ocean is cooler, than the adjacent continents. This uniformity of oceanic temperature is partially communicated to all the islands and shores, so as to constitute a distinct sort of climate, which is less subject to extremes either of heat or cold than that of the interior of continents, and is more uniformly charged with aqueous

vapour. We have therefore the following scale of climates in relation to latitude:—

$$\text{Equatorial}\left\{\begin{array}{l}\text{Mountainous}\\ \text{Continental}\\ \text{Littoral}\\ \text{Marine}\\ \text{Pelagian}\end{array}\right\}\text{Polar.}$$

In agreement with what was before observed, we need not take into account the animals and plants of the pelagian or deep sea, or those which dwell on the mountains of very cold countries. Of the other climates, we may investigate some of the characteristic organic forms very simply.

First, of terrestrial climate as indicated by plants. Humboldt and other scientific voyagers present us with landscapes of the tropical regions, in which the magnificent Palms, the princes of the forest, are surrounded by Bananas, Cycadeæ, arborescent Ferns, Bambusiaceæ, Equisetaceæ, Lycopodiaceæ, Cacti, Euphorbiæ, and Mimosæ. To enjoy the splendid aspect of the tropical plants in the colder zones, we must imitate the tropical climates by hot stoves. In the elevated parts of the tropical continents, which have a climate comparable to that of northern latitudes, occur Cypresses, Pines, and Oaks. It is along the moist shores, and on the small islands of the warm zones of the earth, that arborescent Ferns, and Cycadeæ,

and Equisetaceæ grow in the greatest abundance, so that in these situations they form a very large proportion, even to half the total number of plants. In the drier interior of the continents, on the contrary, arborescent Ferns are less abundant; but Palms, and especially the succulent Cacti, form the characteristic vegetation. If we suppose that by any means the plants of an ancient tropical region of varied surface were buried under marine sediments, and by subsequent revolutions affecting that part of the globe these altered reliquiæ were laid dry and exposed for examination, the ancient character of the climates, when and where these plants grew, could be satisfactorily inferred, *provided* that, in the actual system of nature, plants of analogous tribes were found really limited in their situation by circumstances depending on climate. Now this is precisely what happens in the case of fossil plants; for the most abundant and characteristic forms of ancient vegetation are Ferns, some of them arborescent, Lycopodiaceæ, Equisetaceæ, Cycadeæ, Palms, and Cacteaceæ. With these, or in separate layers, occur coniferous trees, and other plants, apparently indicative of cold regions or elevated land. Upon the whole, it seems the most probable inference, that the abundant vegetation of our coal strata was the produce of a warm and damp region, varied with plains, and shores, and mountains. The state of

conservation of the plants, covered with leaves and in a state of considerable perfection, seems to prove that they have not been washed from a great distance; if so, the *places* where they are buried had the same sort of climate as warm regions of the earth in its present state.*

If this conclusion be sound, it will be difficult to avoid believing that nearly the same warmth of climate was felt at the same time in those parts of the globe where now are New Holland, Greenland, North America, and Europe; for in all these countries, plants belonging to the same or very analogous species lie in a deposit of the same geological antiquity — the carboniferous system. Humboldt long ago expressed the necessary consequence of this pervading high temperature, by saying, that in this condition of the world there was properly *no peculiarity* of climate, but a general superficial warmth, depending on the then greater or nearer influence of the interior heat.

In the existing economy of nature, terrestrial climate is supposed to be in a remarkable manner indicated by the races of vertebral and invertebral animals; but in the application of this principle a

* If the river rolled as far as the Mississippi, cold regions and hot might equally yield reliquiæ to a basin which should be in a temperate zone; or in other ways the inferences might be varied. Currents of the Atlantic bring timber from the tropical shores to Ireland and Iceland.

difficulty occurs, which is, in a less degree, also experienced in geographical botany. Animals are limited in their distribution by other causes than climate; they are localised between certain chains of mountains, certain breadths of deserts, and particular arms of the sea, and not unfrequently confined even to particular valleys and islands. Moreover, the remains of terrestrial animals are scarce in the earth; and it is perhaps only by a comparison of the forms of reptiles that any trustworthy results can be derived concerning the climate of the land in the northern zones of the world during any part of the period of stratification. Even here the conclusion is not very applicable to the land, because most of the fossil reptiles were marine. While, however, the ichthyosaurus and plesiosaurus might be littoral, and the crocodiles were probably estuary and river animals, the megalosaurus and iguanodon might live along the margins of primeval lakes; and from the whole series of these gigantic beings, compared with the present saurians and other reptiles, we may be well justified in inferring, that as all large reptile forms are almost peculiar to the warm regions of the globe, so it most probably was in the older time.

The existence of zoophytic animals is subjected, in a very decided manner, to the influence of warmth at small depths in the ocean, and there-

fore these will furnish the best possible evidence for the temperature of the ancient sea. If we confine our attention to the polypiferous and spongiform zoophyta, we shall find that the stony corals generally, including the madrepores, millepores, and tubipores of old writers, belong to warm seas, as the West Indies, East Indies, the South Pacific, Red Sea, Mediterranean, &c., and hardly appear abundant in any part of the ocean beyond the 33rd parallel of latitude (except along the south-east coast of Australia). The older calcareous strata are so full of remains of stony corals, that they have been considered by most geologists as coral-reefs, analogous to those which, in shallow parts of the seas, grow up, like the Bermudas, a mingled mass of coral, shells, and calcareous mud derived from the comminution of these materials in the currents of the sea.

The *corticiferous corallines*, like Gorgonia, Isis, &c., appear equally determined in their general distribution to the warm shores of the sea, but their number in a fossil state is too inconsiderable to serve as the basis of analogical reasoning.

The *celluliferous corallines*, like Flustra, Sertularia, and Cellaria, appear, on the contrary, most abundant in the temperate and colder zones as far north as 60°; but they are of comparatively rare occurrence in a fossil state. Sponges give us some curious results. These half-animalised

beings contain, in their durable parts, spiculæ of calcareous or silicious matter, with more or less of a horny substance. In proportion as the horny matter increases in quantity, and ramifies and reunites itself into network, the sponges are more flexible and more useful: those which consist principally of earthy fibres are too harsh for use. The horny sponges belong to warm seas, and especially to southern seas, where, as on the shores of New Holland, they grow even in temperate latitudes. The silicious and calcareous sponges are plentiful along the coasts of Great Britain, even to the northern parts. Fossil sponges are much more analogous to the horny than to the earthy kinds.

There would be little advantage in extending this investigation to the Mollusca, Crustacea, or fishes which dwell in the sea; because these animals inhabit various depths in the water, sometimes migrate periodically to the shores, and are not sufficiently characteristic of climate, except by analysis of the families too minute for our argument.

We have thus found (after limiting our investigations to such organic races as are eminently and in large groups characteristic of climate in the actual economy of nature, and are also plentiful in a fossil state,) clear indications that the ancient climate on the land was such, over a great portion of the globe, as to nourish plants of

tropical forms; that the water of the ocean in the same regions, at small depths, was of such temperature as to permit the growth of coral-reefs, and the existence of large reptiles. And as these conclusions will not admit of explanation by calling in astronomical causes, *which probably have not acted*, such as the displacement of the earth's axis, or *others which are not sufficient*, as change of the earth's distance from the sun, we have only two hypotheses to choose between, or to combine. Either we must suppose the local elements of climatal variation to have gone to such an extreme as to nourish tropical forms in arctic zones, or allow that the superficial warmth of the earth was in a great degree regulated by the communication of heat from within. If we adopt the latter alternative, we must view the globe as now cooled at the surface, owing to the accumulation of non-conducting solid rocks over an ignited nucleus, and governed in its temperature by the external influence of the sun.

But geology has yet another phenomenon to be considered before quitting the subject of the earth's ancient climate. There is reason to think that during very late geological (probably pre-historical) periods, the same northern zones of the earth, which in earlier times had nourished plants and animals resembling those within the tropics, were *chilled* by a general reduction of tem-

perature; so that the mountainous regions of Britain and Ireland were covered with perennial snow; their rugged valleys filled with gliding glaciers; the seas at their feet filled with arctic life, and covered by floating icebergs, loaded with rocks from the Mourne, Grampian, Cumbrian, and Cambrian mountains. The *proof* of this in regard to the ancient sea was first presented in a distinct form to geologists by Mr. James Smith*, in 1839, and has been applied in extensive generalisation by Professor Edward Forbes†, in 1846. In general terms we may say that in connexion with some of the later and more superficial deposits — parts of the sea bed, and remains of sea beaches — are *found* above a hundred species of shells, which are now living in the British oceans, and also in seas more to the northward; while a much larger number of the shells now living in the British seas, whose affinities are to the southward, are wholly and constantly *absent* from the deposits in question. Certain shore shells, as *Littorina expansa*, found in the "glacial" deposits, are still living in the Arctic, but not known in the British seas.‡

* Memoirs of Wernernian Society, vol. viii.

† Memoirs of the Geological Survey of Great Britain, vol. i.

‡ See on this whole subject De la Beche's Geological Observer.

In regard to the icy character of the land, we find in all the mountain regions already named, clear positive traces of the *gliding of glaciers* down many of the valleys; parallel striæ, surfaces smoothed by long and equal friction, heaps of *moraine.* Even the movement of the icebergs, which broke off at the seaside from these glaciers, can be traced by the blocks of rock which on the melting or overturning of the "berg" were dropped on the bed of the sea. Thus from Shap-fell, in Westmoreland, the blocks have been floated on ice, and drifted by currents, over the hills of Yorkshire and the plains of Lancashire; from the porphyritic summits near Bala Lake, the masses have been conveyed on to the plateaux of the limestone ranges in Flintshire.

It might, perhaps, be imagined that the *higher degree of cold* which prevailed on the mountains of the north of Europe (we might include Asia and America) was explicable by supposing the whole country to have been *more elevated.* But the facts already proved — viz. the dispersion of "erratic blocks" on icebergs, and the diffusion of marine shells in connexion with the glacial drift, — are inconsistent with that condition. They require, indeed, the admission of the very reverse, and *prove* that the "glacial sea" had its level about 1500 feet higher than the present sea, or

(which, geologically speaking, is more correct) that the British land was 1500 feet lower.

This, which at first view seems to increase the difficulty of explaining the peculiarities and changes of ancient climate, opens in reality a way to account for the *greater cold* of the northern zones. For it shows that the cold was preceded by a great subterranean movement,—a change of the land and sea. If by such a change, happening at the present day, the flow of warm water from the equatorial regions, by the tidal wave and the gulf stream, were cut off from the north-western parts of Europe, our temperature, now higher by ten or twenty degrees than that of the corresponding latitudes in Eastern America, would lose all this advantage, and might again witness unmelted snows on Ben Nevis and Helvellyn, and icebergs on the surrounding seas.* The British Islands, and the west coast of Norway, are situated on what is now the warmest meridional band on the globe; by a change of circumstances at the surface, quite within the acceptance of geologists, it might become one of the coldest. But by no change of a contrary kind is it conceivable, that that which is now the warmest band could be heated ten or twenty degrees more; still less that such a great addition of warmth could be

* Hopkins, in Geol. Proceedings, 1853.

communicated at the same time to a large part of the northern zones, and continued through long geological periods.

We cannot, therefore, dispense with the supposition which seems obviously indicated by the phenomena, that the internal heat, which is still sensible at small depths below the surface, was formerly much *more sensible*, and that it effectually influenced, and really exalted, the temperature of the now refrigerated lands and seas of the north.

EARLY RACES OF ORGANIC BEINGS.

Were one who was completely ignorant of geological science required to consider the question whether this globe had been tenanted in some ancient periods by races of animals and plants different from those which now inhabit it, he would perhaps be surprised at the novelty of the idea, but would find himself unable to answer. History, it is evident, can tell us nothing of those times which preceded the existence of man: there is nothing in the Mosaic records of the creation of man, and the present forms of organic life, which in any manner defines the earlier condition of the globe, further than by affirming that it was formerly in a different state, especially as to its enrichment with living beings, from that which it exhibits to us at present. This latter

consideration is too little present to the minds of many sincere readers of the Bible: and, in consequence, a very unhappy conflict has been sometimes occasioned by comparing those results of geology which relate to periods left wholly undefined in the Scriptural narrative, with the successive works of creation which are in that narrative distinctly marked. If we take the first words of Genesis as containing a general affirmation in regard to the prior conditions of the world,—from the epoch of its original creation until The Maker saw fit to appoint its present character, and to call into being its present races of man, animals, and plants,—and compare this with geological inferences relating to periods anterior to man, we shall find two conclusions inevitable; first, that there is no word in the Scripture narrative which limits in any way the inferences or even the speculations of geology, with reference to those periods; secondly, that nothing can ever be learned about them by human labour, except in the way of geological induction. This is sufficient for the purpose of the present inquiry, which relates to races of animals and plants, not only anterior to man, but even to the elevation of most parts of our continents from beneath the waters of the ocean.

Recurring to the observations concerning the lapse of time which took place during the forma-

tion of the stratified crust of the globe, we shall be prepared to enter on a more extended inquiry concerning the races of animals and plants than was necessary in a former section.

The number of species of plants and animals at present in existence is not known even nearly to accuracy, but the following estimate may perhaps be accepted as affording a useful notion of the *relative* proportions.

	Living.		*Fossil.*
Plants - -	80	to	1
Zoophyta - -	2	„	1
Mollusca - -	10	„	10
Articulosa - -	150	„	1
Fishes - -	10	„	1
Reptiles - -	2	to less than	1
Birds - -	8	„	1
Mammalia - -	2	„	1

The actual system of organic beings is adjusted to terrestrial and aquatic life; and of aquatic animals, some live in the sea, others in fresh water. The following Table gives a comparative estimate of recent and fossil plants and animals according to these conditions.

	Recent.		*Fossil.*
Terrestrial.—Chiefly Plants, Articulosa, and Mammalia - -	100	to	1
Freshwater.—Chiefly Mollusca, Articulosa, Fishes, and Reptiles -	10	„	1

	Recent.		Fossil.
MARINE.—Chiefly Plants, Zoophyta, Mollusca, Articulosa, Fishes, and Reptiles - - - - -	2	to	1

From these comparisons it is immediately evident that by far the larger relative proportion of fossil organic remains belongs to the marine division, that the fewest of all are the terrestrial races. This might have been foreseen, for as, when contemplating the strata, we are looking upon the *bed of the ancient sea*, we ought to expect marine remains abundant, and terrestrial reliquiæ very rare. At the present day, only a very small proportion of animals and plants, inhabitants of the land, is carried down to the sea, or even deposited in freshwater lakes.

It has not been found necessary, in discussing the history of fossil plants and animals, to constitute a single new class; they all fall naturally into the same great sections as the existing forms. Thus, among plants, both recent and fossil, occur the same leading classes, founded on the cellular or vascular structure, and on the floral and seminal parts of the plant; among Zoophyta, we distinguish recent and fossil Polyparia and Radiaria; among Mollusca occur all the divisions of Brachiopoda, Conchifera, Gasteropoda, Heteropoda, Pteropoda, and Cephalopoda; among Articulosa we find Crustacea, Insecta, Annulosa, &c.;

and among vertebral animals, Fishes, Reptiles, Birds, Mammalia. Moreover, on analysing these classes, and comparing the subdivisions, families, and genera, we find very often, especially in the marine tribes, that the same characters will apply equally well to both the recent and fossil races. Thus, among conchiferous Mollusca we have both recent and fossil shells with two lateral muscles (Plagimyona), shells with one (principal) subcentral muscle (Mesomyona), and shells of a particular and still different construction (Brachiopoda). Again, in Plagimyona some have many teeth at the hinge (Arca, &c.); others striated hinge-teeth (Trigonia); some large ligamental teeth (Mya); some gape at the ends (Lutraria); some bore holes in rocks (Pholas, Lithodomus), &c. All these and many more characteristic forms and habits occur in both recent and fossil shells. Now as these divisions are all founded upon important points of structure, we are warranted in concluding that the older organic creations were formed upon the same general plan as the modern. They cannot, therefore, be correctly described as entirely different systems of nature, but should rather be viewed as corresponding systems belonging to different periods, and composed of different details.

The difference of these details arises mostly from minute specific distinctions; but sometimes,

especially among terrestrial plants, certain crustacea, and reptiles, the differences are of a more general nature, and it is not possible to refer the fossil tribes to any known recent genus, or even family. Thus we find the problem of the resemblance of recent and fossil organic beings to resolve itself into a general analogy of system, frequent agreement in important points, but almost universal distinction of minute organisation. Of 10,000 fossil species well examined, not more than two or three hundreds are *identical* with living species. Of 1000 genera which include those species, more than half are peculiar to the fossil state.

GEOLOGICAL DISTRIBUTION OF ORGANIC REMAINS.

Remembering that each set of stratified rocks was successively the bed of the sea, and that the organic exuviæ which lie in these rocks are parts of animals and plants then living in the sea or on the land, we shall be able to compare the organic beings of the several periods of the stratification of the earth's crust with each other as well as with existing tribes. If out of the series of strata, taken in general terms, we select six groups or systems, as under, beginning with the least ancient, viz.,—

Tertiary system,	Saliferous system,
Cretaceous system,	Carboniferous system,
Oolitic system,	Silurian system;

and consider the numerical relations of the organic fossils which have been found in these several groups in various parts of the world (separating, for the sake of perspicuity, the marine from the fluviatile and terrestrial reliquiæ), we have the following results:—

The first Table relates to marine tribes.*

	Plants.	Zoophyta.	Mollusca.	Articulosa.	Vertebrata.	Totals.	General Thickness of Strata.	Number of Species to 100 feet thickness.
Tertiary	13	49	2,728	5	26	2,821	2,000	141
Cretaceous	14	235	500	13	15	777	1,100	70·7
Oolitic	4	275	771	22	70	1,142	2,500	45·6
Saliferous	6	15	118	1	24	164	2,000	8·2
Carboniferous	?	84	366	10	10	470	5,000 to 15,000	4·7
Silurian	4	122	349	65	?	540	20,000 or more	2.7 or less

This Table shows, in a very striking manner, the fact of the far greater abundance of marine organic exuviæ in the newer than in the older

* The Table was drawn up twenty years since, and requires enlargement in every one of the numbers; but I leave it unchanged (except by writing Silurian for Primary) because the main inference which it teaches is still correct.

strata, and seems to add a strong argument in favour of the prevalent opinion, that the lowest of all the primary strata were formed in a period when the ocean was devoid of living beings. If this conclusion be correct, the archives of nature are almost completely preserved to us, and the history of fossils is that of nearly the whole series of living beings which have successively inhabited the ocean.

Let us now turn our attention to the terrestrial reliquiæ, which are less abundantly diffused through the same systems of strata. We shall confine ourselves to plants of undoubtedly terrestrial and lacustrine origin.*

	No. of Species.	Thickness.	Number of Species to 100 feet thickness.
Tertiary - - -	156	2,000	7·8
Cretaceous - -	7	1,100	0·7
Oolitic - - -	76	2,500	3·0
Saliferous - -	40	2,000	2·0
Carboniferous - -	274	10,000	2·7
Silurian - - -	1	20,000	0·005

For various reasons, we cannot venture to draw any inferences from these data as to the relative numbers of plants really existing on the land during these periods. The principal difficulty

* Drawn up above twenty years since. The numbers for fossils are too small, in all but the oldest strata.

arises from the obvious fact that the occurrence of terrestrial reliquiæ at all in the marine deposits is *accidental*.

We may now advance to another view of the subject of the distribution of organic remains in the earth. We may inquire whether the fossils which occur in all these great systems of strata, and which differ more or less completely from existing forms, be indefinitely distributed through the different groups of strata, or whether the series of fossils in each system of strata be distinguishable from those in the other systems. To this the reply is short and decisive. Wherever examined, the several systems of strata above enumerated contain wholly distinct suites of organic remains, by which, in every limited district hitherto explored, they may be respectively characterised. As the fossils are distinguishable from recent beings, for the most part by minute differences of organisation, but sometimes by whole genera and families, so the several systems of fossils locally observed differ from one another in the same manner. The Silurian strata, for instance, may be distinguished from the carboniferous system by minute yet clear distinctions in the several species of shells belonging to the same genera of Orthoceras, Leptæna, Spirifera, &c.; from the saliferous system, by the absence in this latter of Trilobites, Orthocerata, and whole groups

of corals; and from the oolitic system, by the presence there of new forms of Ammonites, Gryphææ, Trigoniæ, Pholadomyæ, &c.

On this subject, two propositions may be adopted; first, The amount of the differences observable between the fossils of any two systems of strata is greatest in those systems which are the furthest removed, as, for instance, between the primary and the tertiary systems; secondly, The amount of the differences observable between the fossils of any system of strata and those at present in existence is greatest in the oldest system of strata, and least in the newest. Thus, on placing together primary fossils and recent shells of zoophyta, the difference is striking and total; but on comparing tertiary and living forms, it is the resemblance which arrests our attention. In one case we see at a glance the most obvious and complete discordance; in the other it requires careful scrutiny to assure ourselves that they are not identical. Viewed in this manner, the whole living and fossil world of existence, as far as relates to the inferior, and especially marine tribes, seems to be almost united into one vast chain of being, which has derived from the same Creator in all past times the same fundamental laws of relation to the conditions of the world, but which shows itself in various forms, because these conditions were made to change. What a lofty

view of the superintending care and providence of God through *all* periods of past time is thus opened to our minds! How heedless of plain truths must they be who can ever disconnect geological inquiries from reverential thoughts of the divine Lawgiver of Nature!

The conclusions above stated as to the entire distinctness of the organic remains in the several systems of strata apply with certainty to every limited region; that is to say, in whatever part of the world, Silurian, carboniferous, saliferous, oolitic, cretaceous, and tertiary systems have yet been seen together, the fossils which they respectively contain are different from one another. In every country yet examined it is *locally* true that the systems of strata of different age contain distinct races of organic remains. But inquiries of equal importance now present themselves. Do strata of the same age uniformly contain fossils of the same species? Do they contain fossils of analogous species? Or are the fossils which any rocks contain merely of local occurrence, so that in distant parts of the world strata of the same age contain wholly different organic remains?

This is a mere question of fact: it must not be answered by reasoning upon existing phenomena, or by hasty generalisation from limited data. On this subject we have yet much to learn: the following, however, are ascertained truths.

The same *groups of fossils* which are in a very eminent degree characteristic of certain systems in one country, are also found under the same relations to those systems, not only in adjacent, but in far removed tracts, sometimes even to the distance of thousands of miles. Thus, for example, of the extinct crustaceous animals called Trilobites, the far greater portion of those found in England belongs to the Silurian and lower Palæozoic strata; they also appertain in the same nearly exclusive manner to the same system of strata through Norway, Russia, the Harz, Brittany, &c. They also characterise the same systems in North America.

Again, the extinct plants called Lepidodendra characterise, almost absolutely, as a group, the coal strata of Great Britain: they have exactly the same relations to the coal of France, Belgium, Silesia, and North America.

Certain groups of Ammonites belong exclusively to the oolitic system of England: they are equally characteristic of this system in France and Germany, and come to us from the Himalayan mountains associated with other oolitic fossils.

Peculiar forms of Echni mark the cretaceous strata of England, and the same occur in France, Poland, and along the shores of the Baltic.

Whole families of shells, such as Volutes, Cones, Cerithia, &c., may be viewed as dis-

tinguishing the tertiary strata from those below them, in all parts of the world.

Instances are known of certain *peculiar species of fossils* occurring in the same series of strata in almost every region where those strata are known. Thus, the Dudley Trilobite (*Calymene Blumenbachii*) is found in Shropshire, Herefordshire, and Gloucestershire; it also occurs in Norway, in the Eifel, and in North America, but only in the same parts of the primary series of strata. *Calamites Suckovii* occurs in the English coal-fields, and in those of Liege, Anzin, Pennsylvania, and Virginia, but not in any deposit of a different age.

The *general aspect and character* of series of fossils derived from the same system of strata in very distant quarters of the globe are often extremely similar; very generally the same characteristic generic forms are repeated at all points in the ranges of the same strata; but there are also local differences always observable, which become the more considerable and obvious the greater the distance between the localities.

From all these considerations, we may conclude satisfactorily that the organic remains found in any one system of strata are of the same general character wherever these strata occur; that many *local* distinctions derived from organic remains between successive systems of strata disappear

when the facts are viewed on a great scale; but that, as far as our experience at present goes, each system of strata may be identified through its whole course, and discriminated from the older and more recent systems, by a judicious examination of a sufficient number of its organic contents. It is thus made evident that there have been many races of marine animals and terrestrial plants which have been successively called into existence in the same regions of the globe to suit its altered condition, and we may be assured that these successions of organic beings, well understood, will afford a secure and unchangeable scale of geological chronology. What the periods are which this scale of successive creations indicates, we may perhaps never know. There is but one mode of approximation to even a plausible estimate of these periods — a knowledge of the length of life of the different sorts of marine animals. If this mode should be found impracticable, we fear the problem must be despaired of.

It would be impossible, even if it were suitable to the object, to give in an elementary work anything like an extended exemplification of the principles above announced. Fortunately, however, some illustrations can be presented in a tabular form, which will sufficiently evince the truth of these views. If we put in one table

some of those genera which in the present system of nature are most rich in species, and in another those which were most prolific in forms in the older periods, we shall see very clearly what analogy or difference may exist. Also, by selecting other genera and families, we may show through what ranges of strata, that is to say, through what geological periods, they existed, and at what periods they were most numerous. Thus, Trilobites existed during the Cambrian, Silurian, and Carboniferous eras, but are nowhere known in the more recent strata, nor do they exist at present; Productæ pass through the whole of palæozoic periods, and end in the saliferous; Spiriferæ pass through all these systems and end in the oolites; Ammonites pass through all these periods, and end in the chalk; Terebratulæ, which existed through all these periods, and also through the tertiary system, are still in being. On the other hand, certain tribes began to exist at later epochs, as the Belemnite, many genera of Echini, &c., and their races ended before the dawn of the tertiary period. This will serve to render intelligible the following Tables.

TABLES OF THE GEOLOGICAL DISTRIRUTION OF FOSSILS.

Table I. *Genera containing many living species.* (*Gasteropoda.*)

	Cypræa.	Conus.	Voluta.	Strombus.	Murex.	Fusus.	Cerithium.	Mitra.	Pleurotoma.
Living -	*	*	*	*	*	*	*	*	*
Cainozoic -	*	*	*	*	*	*	*	*	*
Mesozoic -		*	*	*	*	*	*		
Palæozoic -									
Hypozoic -									

In this Table, the strong affinity of the tertiary to living forms of animals, and the diminution of this affinity, as we proceed to compare recent life with the remains of earlier date, are very decided.

Table II. *Genera containing many fossil species.* (*Conchifera.*)

	Producta.	Spirifera.	Terebratula.	Trigonia.	Pholadomya.	Plagiostoma.	Inoceramus.	Gryphæa.
Living - -	...	...	*	*	*	...	...	*
Cainozoic - -	...	...	*	...	*			
Mesozoic - -	...	*	*	*	*	*	*	*
Palæozoic - -	*	*	*					
Hypozoic - -								

Tables of this kind suggest curious remarks concerning the duration of existence of certain

genera. The larger asterisks mark the periods of their greatest fecundity in species. From data thus compared, arises an easy distinction of particular sets of strata, by the presence or absence of whole groups of shells, and by the extraordinary plenty of others.

Table III. *Genera of Cephalopoda.*

	Nautilus.	Orthoceras.	Goniatites.	Clymenia.	Ammonites.	Belemnites.	Hamites.	Scaphites.	Baculites.
Living -	*								
Cainozoic -	*								
Mesozoic -	*	...	...	...	*	*	*	*	*
Palæozoic -	*	*	*	*					
Hypozoic -									

The above Table shows, in a strong light, the greater prevalence of Cephalopods in the earlier ages of the world. Yet a few nautiloidal forms continue to this day.

The next Table gives the geological distribution of some sections of Belemnites.

Table IV. *Form of Belemnites.*

In and above Greensand - - -	*			
In and above Oxford Clay - - -		*		
In and above Inferior Oolite - - -			*	
In and above Lias - - - -				*

It is easy to see how important, in questions concerning the relative antiquity of the different groups of the oolitic rocks, is a knowledge of Belemnites, since whole sections of them are characteristic of certain parts of these rocks.

The last Table will show that particular species of fossils are frequently confined to one system of strata. The stars indicate in what strata the species named occur.

Table V. *Species of Mollusca and Zoophyta.*

	Venus equalis.	Plagiostoma spinosum.	Trigonia clavellata.	Avicula socialis.	Producta gigantea.	Calceola sandalina.	Terebratula Wilsoni.	Galerites albogalerus.	Clypeus sinuatus.	Encrinites moniliformis.	Platycrinus rugosus.	Sphæronites tessellatus.	Hypanthocrinus decorus.
Cainozoic	*												
Upp. Mesozoic	...	*	...	...	...	...	...	*					
Mid. Mesozoic	...	...	*	...	...	...	...	...	*				
Low. Mesozoic	...	...	...	*	...	...	...	...	...	*			
Upp. Palæozoic	...	...	...	...	*	...	...	...	...	...	*		
Mid. Palæozoic	...	...	...	...	...	*	...	...	...	...	...	*	
Low. Palæozoic	...	...	...	...	...	...	*	...	...	...	...	...	*

LAPSE OF TIME.

The magnificent spectacle of continents rising gradually or suddenly from their parent waves is calculated to impress upon even the least attentive mind a sentiment of respect for the sublime subjects of geological inquiry. It is hardly possible to avoid looking around for indications of the time required for the subaqueous production of such a

mass of strata, and for their subsequent elevation. Before involving ourselves in the difficulties which beset the research into the source and prior condition of the materials of stratified rocks, we may proceed to examine what evidence they afford of their relative antiquity, and what inferences they will justify as to the absolute length of time consumed in their production.

As the antiquary, who is required to determine the dates of the successive piles of a ruined city, judges by the style and sculpture and state of preservation of the fragments, so the geologist, by deciphering the characters impressed by nature on the rocks, is able to arrange them according to successive eras. If the antiquary be unable to refer his discoveries to historical records, and thus to learn the absolute intervals from one event to another, he is reduced to nearly the same state as the geologist, who desires to ascertain the number of years or cycles of years which elapsed during the formation of the crust of the earth. In both cases certain assumptions must be made before even plausible conjectures can be hazarded. Geology, however, would gain little by even a correct *conjecture* on this subject; and though undoubtedly a vast variety of facts observable in the earth are clearly indicative of definite time, these have been far too little inquired into to give us at present the slightest hope of changing the vague periods

of geology into exact terms of years. The following investigation is therefore not intended to accomplish more than to produce a conviction that a long succession of time elapsed during the construction of the visible crust of the globe.

In the production of strata, which are composed of fragmented materials, of any kind, mechanical forces were exerted; for it is chiefly by the influence of waves and currents that sandy and argillaceous matter is brought to the stratified form. When, therefore, we see even a single sandstone rock composed of some hundreds of regular layers of sand and mica, and compare this with deposits from modern rivers or the sea, we shall feel assured that, in assigning to the accumulation of this rock a considerable space of time, we are proceeding in a just spirit of philosophy.

If we consider the common case of alternating clays and sandstones, both of which are mechanical deposits from water, but produced under different circumstances, perhaps brought in different directions, the indications of the progress of time become perhaps more clear and satisfactory.

It is very common to find deposits of limestone, apparently produced by chemical decompositions, lying in frequent alternation with sandstones and clays; and, in such a case, by inquiring of the actual system of nature, we receive an answer that such changes of the mode of action in a given

place imply cessations and renewals of chemical and mechanical operations which require time.

By reviewing in this manner the whole series of strata, amounting locally to some miles in thickness, and considering the accumulation of each bed, the alternation of beds of different kinds, the excitement, duration, suspension, and resuscitation of mechanical and chemical agencies, we shall be strongly impressed with the folly of setting narrow bounds to the time employed in these operations.

Some stratified rocks are composed of fragments of various kinds, united by a general cement of a different nature. These are called brecciated or conglomerate rocks, according as the fragments are angular, or rounded by attrition in water. Here there is proof that before the production of one stratum a previously stratified rock had been consolidated, partially broken up, its fragments agitated in water, and then redeposited. In some cases, conglomerate rocks have been *again* broken up, and their fragments submitted to a second process of attrition and reaggregation.

There is another class of phenomena which speaks a language on this subject that can hardly be misunderstood. We are well assured of the length of time required for the growth and maturity of organic beings; when, therefore, a single bed of stone, only a few inches thick, is found to contain a given species of shell, in every variety

of magnitude, from the embryo to the full-grown or aged individual, all the specimens having evidently been enveloped quietly on the bed of the sea, and no bed either above or below for 100 yards or more containing any such shells, the conclusion seems certain that even for the accumulation of this one bed of stone the lifetime of that species of molluscous animal was required. Such a case occurs in the coal district of Yorkshire, where a bed of shale only a few inches thick, but extending for many miles, contains *Ammonites Listeri* in every stage of its growth; but that shell does not occur above or below, through a great thickness of strata.

In some cases whole rocks are literally composed of zoophytes, so as to resemble a modern coral reef, or of shells of many kinds. The extensive strata of coal are derived entirely from immense accumulations of vegetables, and sometimes no less than fifty consecutively deposited strata of this kind extend over a hundred square miles and more.

Strata which contain certain tribes of organic remains alternate with others which inclose none, or quite different races. Strata full of marine exuviæ are separated by others full of trees swept down from the land; and thus we are furnished with evidence of intermitting energy among the agents of ancient nature.

It seems unnecessary to accumulate more evidence in order to obtain an unanimous verdict from all impartial readers that the length of time occupied in the production of the strata, some miles in thickness, which exhibit all this variety of events, was really very great. Whether it may hereafter be found susceptible of some rude approximation will depend upon the knowledge we may be able to gain of the rate of stratification and consolidation, and of the length of life of some of the fossil races. Is this expectation wholly chimerical?

PART III.

SERIES OF STRATA.

THE MASS OF THE GLOBE.

GUIDED by the principles, and restrained within the limits declared in the previous pages, we may now proceed to mark some of the main steps in the formation of the crust of the earth.

To penetrate all the mysteries of Creation is not the privilege of the most favoured creature. But it is neither presumptuous nor irrational to inquire into the changes which have happened to created things in consequence of the operation of the appointed *laws* of nature, provided there be *monuments* of such changes. If these monuments be *sufficient, open to observation, and capable of interpretation,* the problem of the "revolutions" which the earth has undergone is not obviously impracticable, though it may be found on trial really too difficult for determinate solution. The earth is the monument of the changes which it has undergone; its spheroidal figure is a measure of

the *mechanical* forces under which its constituent matter has been arranged; this mineral matter is the result of the operation of exact *chemical* laws; and as the forms of life now on the globe are kept in harmony and subordination to the *physical* conditions which these mechanical and chemical laws maintain, so the more ancient series of plants and animals, having been subject to similar laws, but under different conditions, teach us in some degree what these conditions were.

That such teaching is often imperfect, and often hard to follow, none know better than geologists; but no "lover of nature," who sees in all the universe of space and time the steady hand of Divine Providence, will undervalue or neglect to use the privilege by which, quitting the earth, and free from the little measures of days and years, the mind can speculate through boundless space, and associate its thoughts with the long ages that have gone darkly by, and the longer and brighter periods which are yet to come.

The leading facts concerning the earth which are furnished to us by astronomy, become, when interpreted by the aid of the general mechanical theory of the universe, monuments of the earliest physical changes which our planet has undergone. The spheroidal figure of the earth is a necessary consequence of its rotation on an axis; it could only be acquired by a body whose *superficial parts*

were capable of free relative motion. The theory of the lunar irregularities which depend on the earth's spheroidal figure, appears to teach us that, for at least some considerable distance downwards from the surface of the earth, the materials are arranged in conformity with the elliptical outline of the exterior: hence its *interior parts* must have been capable of free relative motion, and it may be very reasonably supposed that they have been in a state of *fluidity*. That such fluidity was occasioned by heat, is a plausible or rather necessary hypothesis, for no other known agent is adequate to the effect. But our confidence in this hypothesis becomes strengthened when we find that the results of careful experiments, repeated in various parts of the world, agree in demonstrating that the interior parts of the earth, at small depths, are now sensibly hotter than the surface, and that this augmentation of heat follows some regular ratio to the depth.

The earth, indeed, appears to be exactly in the condition which the supposition of its former fluidity through heat and long exposure to the refrigerating influence of space would require; cooled at the surface, but, within the external crust, still sensibly warmed by the remains of its original heat. The *nucleus of the globe* may even now be partially fluid with heat. It is no objection to this view, that the surface tem-

perature of the earth is regulated by the sun: this cannot be otherwise while a thickness of solid rock near the surface conceals and stifles all sensible heating effect from within.

The mean density or specific gravity of the whole mass of minerals near the surface of the earth, is about twice and a half that of water; but astronomical and general physical researches concur in proving that the mean density of the whole planet is about five times that of water; consequently the matter in the interior of the earth is heavier than that near the surface. This is all we really know of the *nature of the nucleus* of the earth. Whether the substances of which it consists be of the same kind as some of those near the surface, or of another kind altogether, can only be matter of conjecture.

We may *conjecture* them to be of the same general nature as those thrown up to the surface by modern volcanoes; and perhaps this opinion may be confirmed by the fact, that mineral compounds in several respects like these, and evidently the produce of heat, lie under all the strata, or burst through them from some miles below, thus giving a considerable range of positive information in regard to the crust, but little in regard to the nucleus of the earth.

The next class of monuments from which we may hope to gather information concerning the

most ancient conditions of the globe, are furnished to us by chemistry. Analysed by this powerful science, the apparently innumerable varieties of rocks and minerals are reduced to their elements; and thus all the known ponderable matter of the globe is found to be *composed* of about fifty-eight substances, which we regard as simple or elementary, because they appear incapable of further decomposition.

Of these FIVE exist in a separate state only as gases; viz. hydrogen, oxygen, azote, chlorine (fluorine ?).

SEVEN are non-metallic solids and liquids; viz. sulphur, phosphorus, selenium, iodine, bromine, boron, carbon.

SIXTEEN are metallic, or metalloid bodies, which unite with oxygen to form the earths and alkalies; viz. sodium, potassium, lithium, aluminum, silicium, yttrium, erbium, terbium, didymium, glucinum, thorium, calcium, magnesium, zirconium, strontium, barium.

TWENTY-NINE are what are commonly called metals: manganese, zinc, iron, tin, cadmium, arsenic, antimony, copper, molybdenum, uranium, tellurium, chromium, cerium, lanthanium, nickel, vanadium, cobalt, lead, tungstenum, titanium, mercury, columbium, bismuth, osmium, silver, palladium, rhodium, platinum, gold, iridium.

Oxygen combines with so many of these,

and in such large quantities with the earthy and alkaline metalloids, which are the most predominant ingredients of minerals, that we may venture even to say that *one half of the ponderable matter of the exterior parts of the globe is composed of oxygen gas in a state of combination.* The speculations to which this conducts, as to the concentration from a gaseous condition of the matter of the planetary system, seem to be in agreement with the astronomical views of Herschel and Laplace, but are perhaps beyond the range of geology, which considers not the origin of the globe, but the successive changes of condition which it has undergone, since it acquired its general character as a planet turning on its axis, revolving round the sun, and subject to those appointed agencies which we call the *laws of nature.*

Speculations as to any earlier condition of the matter of the globe—its nebulous expansion, its gradually formed nucleus, the separation of its beautiful satellite, and the like, are *not geological.* They belong to astronomy, and form some of the most inviting pages in that vast and wonderful volume. There is no danger of such subjects being neglected; every day augments the means for these sublime researches; but with whatever result they may be prosecuted, geology can gain or lose little by their success or failure. Perhaps

the tendency to over generalisation, which has marked this line of speculation, may be sufficiently checked by Lord Rosse's discoveries of the *spiral* and *irregular* arrangements of some nebulæ, and the *star-composition* of others.

GRANITIC ROCKS BELOW ALL TRACES OF WATERY ACTION.

Rocks of the granite character, containing felspar, more or less crystallised, in combination with mica and quartz (granite), or with hornblende and other minerals (syenite), or with hypersthene, &c. (hypersthenite), are very extensively found under the lowest of the strata which appear in any given large district of country. Granite is found in many parts of the Highlands, in Arran, under Skiddaw, in Dartmoor and Cornwall, the Mourne Mountains, Wicklow, &c. Syenite is similarly recognised in Malvern, Charnwood Forest, Carrock Fell, Arran, Skye. Hypersthene rocks in Skye, the Valteline, &c.

But the age of these rocks, if dated from their consolidation, is not in general so great as their low position might seem to indicate. Indeed, from these once melted masses, the lowest we can reach, ramifications, also formerly in a state of fusion, rise and pass off in many places to fill fissures in the strata above. From this it follows that in such cases the subjacent igneous rock has

been in fusion since the deposition of the strata which it penetrates by veins and dykes.

HYPOZOIC STRATA, BELOW ALL TRACES OF LIFE.

It is sometimes clearly seen that these strata, where they come in contact with the igneous rock, have themselves undergone fusion and re-arrangement of their particles, so that garnets and other minerals, not elsewhere apparent in them, are produced near the surfaces of contact, and the stratification, everywhere else obvious, is there destroyed or complicated with some new structure, such as prismatization, or other forms which heat is known to produce in rocks. Stratified rocks thus changed in their texture and structure, are generally said to be in a *metamorphic* state, and many geologists regard the whole or a great part of the most ancient strata as in this condition. That this opinion is to *some extent* true cannot be doubted; it is the natural consequence of such strata being buried by the accumulation of others over them, to a depth of some miles; thus they have been brought under the influence of the heated interior of the globe. But that these strata, such as mica slate, gneiss, &c., are to be regarded, *everywhere*, as derived by metamorphism from ordinary sandstones and shales and that their deficiency of organic remains is to

be regarded as one of the effects of this metamorphism, is not proved. The absence of organic remains seems not really due to a recrystallization of the matter of these rocks; for in some of the strata above them, which have not undergone metamorphism to such an extent as to destroy organic remains, these are, nevertheless, very rare, comprised within very few genera and species, and seem to be finally lost in going downwards, as we might expect them to be on approaching the earliest dawn of created life.

The reader may now consult with advantage the general scheme of stratification, suited to the British Islands, which is presented on page 114. In the first column are the most general titles of groups of strata derived from the widest view of the systems of ancient life; in the second column the relative thicknesses of the several minor groups, or "formations," appear; in the third the names by which they are designated in this work. As examples, merely, of the employment of the useful term "system," to bring together allied formations, these groups are thus combined in a fourth column.

CAINOZOIC		Post-Glacial	PLEISTOCENE	(Lyell.)
		Glacial	PLEIOCENE	
		Preglacial	MEIOCENE	
		Eocene	EOCENE	
MESOZOIC	UPPER	Chalk	CRETACEOUS	
		Greensand		
		Wealden		
	MIDDLE	Upp. oolite	OOLITIC	
		Mid. oolite		
		Low. oolite		
		Lias		
	LOWER	Red Marl	SALIFEROUS	
		Red Sandstone		
PALÆOZOIC	UPPER	Magn. Limestone	PERMIAN	(Murch.).
		Coal measures	CARBONIFEROUS	
		Millstone Grit		
		Yoredale Rocks		
		Scar Limestone	DEVONIAN	(Lonsd.).
	MIDDLE	Old Red and Devonian		
	LOWER	Ludlow	SILURIAN	(Murch.).
		Wenlock		
		Caradoc	SILURIAN; CAMBRIAN	(Murch.); (Sedgw.).
		Llandeilo or Bala	SILURIAN; CAMBRIAN	(Murch.); (Sedgw.).
		Trappean group under Snowdon	CAMBRIAN	(Sedgw.).
		Lingula beds		
		Barmouth beds		

HYPOZOIC STRATIFIED AND UNSTRATIFIED ROCKS.

We shall now describe the various stratified masses which have been successively deposited by water, and cover in extensive sheets the granite skeleton of the earth; beginning from below and proceeding gradually upwards, or, in other words, passing from the oldest to the most recent.

THE GNEISS SYSTEM.

Thickness. Variable, sometimes amounting to a few miles (Highlands).

Mineral Character. Beds of *gneiss*, consisting of laminæ of quartz, felspar, and mica; beds of *mica schist, quartz rock, limestone, hornblende schist,* and *clay slate.*

Stratification. Irregular; the laminæ frequently contorted, undulated. Mr. Sharpe is of opinion that much of the "foliation" of gneiss is not due to the original deposition but to a subsequent rearrangement analogous to "slaty cleavage."

Subdivisions. The series of gneiss rocks, with the admixtures noticed above, hardly admits of any clear subdivisions. In several foreign countries the alternations of members of the gneiss, mica schist, and clay slate systems are frequent. In the Highlands, gneiss, mica schist and hornblende schist, quartz rock, and limestone are variously associated.

Physical Geography and Localities.—In the western isles of Scotland, the northern and western Highlands, are great breadths of these picturesque and interesting rocks. They contain no *organic remains.*

MICA SCHIST SYSTEM.

Thickness. Variable from a few feet or yards (Cumberland) to a few miles (Highlands).

Mineral Character. Beds of *mica schist,* consisting of quartz and mica, with or without felspar and garnets; of *chloritic schist, talc schist,* &c., in which chlorite, talc, &c., replace the mica; of *quartz rock;* rocks passing to clay slate with laminæ of mica, chlorite, talc, hornblende, &c. Limited beds of limestone, iron ore, &c.

Stratification. A minutely undulated character of lamination belongs to the mica schist system: it is least evident in the limestones, and most striking in the chloritic varieties of schist. Contortions in the mica schists appear most frequently along and near to the axes of anticlinals, as at the head of Loch Lomond. The laminæ are sometimes separated by small irregular cavities, lined with crystallised quartz and mica. How much of these curious laminations is due to original settling from agitated water, and how much to the metamorphic actions which have probably generated garnets, and lined the cavities already alluded to,

is a subject on which new and critical observation would not be misemployed.

Subdivisions. It is generally found that those schists which most resemble argillaceous slate lie in the upper part of the system; the most quartzose and felspathic portions lie toward the bottom; the limestone occurs in detached masses along certain surfaces of deposition in the mica schist.

Physical Geography and Localities. The Scottish Highlands, and the district of Donegal, exhibit these rocks in their greatest masses and noblest forms; and the general effect is heightened by sea-lochs and picturesque lakes and islands, often agreeably wooded.

Organic Remains. None.

LOWER PALÆOZOIC STRATA.

CAMBRIAN SYSTEM

of Sedgwick, containing the earliest traces of life.

Thickness. From one to five miles.

Mineral Character. Argillaceous, indurated, fissile slate rocks; compact, fine-grained, or coarse sandstones; conglomerates; trappean bands.

Stratification. Often difficult to trace in the slate rocks, except by careful attention to the alternation of the coarse, gritty, and conglomerate rocks, and by bands of colour.

Cleavage. This characteristic structure of slate rocks may be described as a natural fissility

parallel to one certain plane, which almost always differs from the laminæ of deposition. Cleavage is most perfect in thick masses of fine-grained argillaceous rock; but even very coarse-grained rocks in the region of Snowdonia are rudely fissile. The cleavage through great part of North Wales is limited in direction between N. 28° E. and N. 35° E. Where the beds of argillaceous rocks are thin and dissimilar (as at Aberystwith), the cleavage structure pervades the fine-grained beds only: in other cases cleavage may be seen to traverse coarser and finer beds, the former more transversely, the latter more obliquely; the two sets of cleavage planes often gradually passing into one another by a short curvature.

It is frequently observed that the planes of cleavage and great axes of stratification have the same strike (*i. e.* coincide in a horizontal line), but the cleavage is often more highly inclined than the strata, so as generally to approach a vertical position. If strata are vertical, cleavage may be inclined. If the strata are curved, cleavage may be in planes. The effect of lateral pressure as a concomitant of cleavage, and directed across its planes, is evident in many ways; by the folding of the surfaces of deposition, in wrinkles parallel to the edges of the cleavage laminæ, and by the distortion of the figures of organic remains. Pressure, heat, and electrical

currents have been cited as the causes of cleavage. One thing is certain,—the particles of the slate have undergone displacement with respect to their *mutual distances*, and their *mutual angular positions*, and they have become fixed in these new relations. Many rocks associated with slates do not admit of cleavage; but throughout all these ancient deposits the joints present a great degree of local symmetry, and, when they have been sufficiently studied, will probably combine, with the constancy of the direction of cleavage, to indicate some general geometrical relations of great importance in physical geology.

Subdivisions. Perhaps the districts of Snowdon and Cader Idris, the scene of Sedgwick's long labours in North Wales, offer the best known general section. Here above the Micaceous System (such as it is) of Anglesea, we have a vast series of sandstones, conglomerates, black slaty beds, and purple slates, which, up to this epoch, have yielded no trace of organic life.

Above are other purple slates, and arenaceous and conglomeritic beds, intermixed with *contemporaneous* layers of felspathic porphyry and greenstone occupying the slopes and buttresses of Snowdon, and well shown in the valleys of Llanberis and Nant Frangon. Deep in this group are certain gray laminated argillaceous parts yielding fossil shells of the genus Lingula, perhaps the

most ancient traces of molluscous life in the rocks of the British Islands. Taken together, they constitute the Lower Cambrian Group of Sedgwick, by whom and by Murchison they have also been sometimes not inconveniently designated "Protozoic."

Physical Geography and Localities. To this fine series of rocks the highest and most picturesque mountains of Cumbria and Wales owe their striking features, and the beauty of the lakes which spread between their bases is much enhanced by the bold outlines and angular masses of their slaty and porphyritic boundaries.

Organic Remains. As yet very few. But it is hardly credible that Lingulæ will be found the only mollusks, Hymenocaris and Olenus the only crustacea of the vast Lower Cambrian group.

LOWER SILURIAN.

We now enter a kindred group of strata to which the above name was applied by their great investigator on the Welsh border, Murchison; while the same series, seen under different aspects, and under more complicated variations, in the interior of the principality, was classed by Sedgwick as the upper part of his great CAMBRIAN SYSTEM.

Fortunati ambo; si quid mea carmina possunt,
Nulla dies unquam memori vos eximet ævo.

If for Lower Silurian we read CAMBRO-SILURIAN GROUP, the alliances of nature will be in some degree represented by terms which will preserve the memory of a long friendship in science.

LLANDEILO FORMATION.

Thickness. Indefinite, and variable; 1000 to 2000 feet about Llandeilo, greater about Bala and Coniston.

Mineral Character. Beds of dark-coloured flags, locally calcareous, with shale, sandstone, and conglomerate.

Localities. Near Shelve, Shropshire; near Builth; Llandeilo; Bala; Coniston Waterhead. At this place the rock is subject to slaty cleavage.

Organic Remains. Numerous. Among them, as yet, no land plants, few or no lamellibranchia, no fishes. *Polyparia* abound, as Catenipora, Petraia, Favosites, Graptolithus, Stromatopora, &c. *Echinodermata* include Hemicosmites, Caryocystites, and a Starfish. The *Brachiopoda* are numerous, including Lingula, Orthis, Atrypa, Leptæna. *Gasteropoda* rare, *Cephalopoda* represented by Lituites, Orthoceras. The *Crustacea* include only Trilobites, as Olenus, Ogygia, Asaphus, Trinucleus, Agnostus, which are for the most part *characteristic.*

CARADOC FORMATION.

Thickness. Variable (500 to 1000 feet), diminished by the removal of the upper group to the series above.

Mineral Character. Conglomerates and sandstones, of various quality and colour, sandy and gritty, sometimes containing traces of volcanic eruptions. In the Malvern district a thick bed of black trilobitic shales.* Limestones.

Localities. The lower parts of the Palæozoic groups of Malvern. Caradoc, in Salop. Coniston.

In some tracts, as in the Malvern Hills, these beds, owing to some peculiarity of their deposition, contain almost no organic remains, except marine plants. The series of shells, corals, and trilobites, collected from these strata in Salop and in Westmoreland, is on the whole closely allied to those of the Llandeilo group, from which, indeed, the diminished Caradoc is not always separable. The more laminated rocks above, which we here call "Upper Caradoc," or Mayhill sandstone, are very full of them, at least in a certain zone.

* In these shales oleni and agnosti occur; the former might seem to claim a higher antiquity, but Sedgwick has found them associated with Caradoc beds on the borders of Wales.

UPPER SILURIAN GROUPS.

UPPER CARADOC OR MAY HILL SANDSTONE.

Thickness. Two to five hundred feet.

Mineral Character. Thin sandstones and shales, with limestone bands overlying; at Malvern and May Hill, thicker masses of coarse or conglomeritic sandstone.

Localities. Shropshire, as west of Ludlow; interior of Woolhope Forest; west side of Malvern Hills; May Hill. The sections in all these localities agree in showing, over a thick mass of sandstones and shales, many thin bedded alternations of sandstones and shales, which enclose the limestones of Woolhope.

Organic Remains. These are undoubtedly, for the most part, of the type of the Upper Silurians, though from the mineral affinities of the rocks they were first classed by the author of the Silurian System in his lower division.* To fit the case of transition, I proposed for the upper part of the group the name of Upper Caradoc†, but Sedgwick has lately carried the line of division lower, and has separated it entirely under the title of May Hill sandstone.‡

The fossils of the Woolhope limestone clearly

* Silurian System, 1837. † Geological Survey, 1848.
‡ Geological Journal, 1853.

unite this rock with the Wenlock series of life; the sandstones above and below contain several fossils of the same age, and there would be no practical inconvenience in comprising all these beds in the Wenlock formation, as the third and lowest member of it.

WENLOCK FORMATION.

Thickness. Seldom amounting to 1000 feet.

Mineral Character. Strata of limestone and shale.

Subdivisions.

Upper Part. A mass of grey and blue nodular and bedded limestone with shale (Wenlock limestone).

Lower Part. Argillaceous shale, liver and dark gray coloured, rarely micaceous, with nodules of earthy limestone (Wenlock shale).

Localities. Dudley; Wenlock Edge; Woolhope; west side of Abberley and Malvern Hills.

Organic Remains. Marine plants, retaining the red tint, are found in the Wenlock Shale near Wigmore.

Polyparia. Very abundant in the limestone, of which they often constitute a large proportion. In the shale scattered specimens occur. Among them Acervularia. Aulopora, Catenipora, Cyathophyllum, Favosites, Fenestella, Graptolithus, Limaria,

Heliopora, Ptilodictya, Syringopora, Stromatopora, &c.

Echinodermata. Actinocrinites, Cyathocrinus, Dimerocrinites, Hypanthocrinites, Palechinus.

Brachiopoda. Lingula, Orbicula, Atrypa, Hypothyris, Leptæna, Orthis, Pentamerus, Spirifera.

Lamellibranchiata. Cardiola, Pleurorhynchus, Orthonota, Goniophora, Mytilus, Cleidophorus, Avicula.

Gasteropoda. Euomphalus, Loxonema, Nerita, Pleurotomaria.

Pteropoda. Conularia.

Heteropoda. Bellerophon dilatatus, &c.

Cephalapoda. Orthoceras, Lituites, Phragmoceras.

Crustacea. Acidaspis, Calymene, Cybele, Dalmannia, Illænus, Phacops, Proetus, &c.

Annelida. Cornulites, Tentaculites.

Characteristic Fossils. Acervularia Baltica, Actinocrinus moniliformis, Hypanthocrinus decorus, Orthis rustica, Euomphalus discors, Conularia Sowerbii, Bellerophon dilatatus, Orthoceras annulatum, Cybele variolaris, Phacops Downingiæ, Illænus Barriensis, &c.

LUDLOW FORMATION.

Thickness. In the Malvern and Woolhope tracts 1000 to 1200 feet. Near Builth, 3188 feet.*

Mineral Character. Beds of sandstone, shale, and limestone.

The sandstones and shales constitute by far the greater part of the formation: the former are slightly micaceous, gray, or dark-coloured, and laminated; the latter are liver or dark-coloured. The limestone is gray or blue, argillaceous, and subcrystalline.

Subdivisions. Tilestone.

Upper Part. Laminated gray sandstone (Upper Ludlow).

Middle Part. Limestone (Aymestry limestone).

Lower Part. Sandy dark gray shale and flag, with concretions of earthy limestone (Lower Ludlow).

Localities. Sedgeley; Ludlow Castle; Aymestry; edge of Woolhope Forest; west side of the Abberley and Malvern Hills. Kirby Lonsdale in Westmoreland.

Organic Remains. Marine plants.

Polyparia. Alveolites, Cyathophyllum, Cystiphyllum, Favosites, *Graptolithus*, Stromatopora.

Echinodermata. (Rare.) Cyathocrinus.

Brachiopoda. Lingula, Orbicula, Atrypa, Hy-

* Dela Beche, in Mem. Geol. Survey, vol. i.

pothyris, Leptæna, Orthis, Pentamerus, Spirifera.

Lamellibranchiata. Cardiola, Orthonota, Goniophora, Cleidophorus, Avicula.

Gasteropoda. Cyrtolites, Euomphalus, Loxonema, Murchisonia, Nerita, Pleurotomaria, Turbo, Turritella.

Pteropoda. Conularia, Theca.

Heteropoda. Bellerophon.

Cephalopoda. Orthoceras, Lituites.

Crustacea. Beyrichia, Cytherina, Calymene, Cybele, Dalmannia, Proetus, Homalonotus.

Annelida. *Serpulites*, Cornulites, Tentaculites, Trachyderma.

Fishes. Spines and other parts of a few, mostly small, species occur in the Upper Ludlow group. None known below Aymestry limestone.

Characteristic Fossils. Lingula Lewisii, Orbicula rugata, Hypothyris navicula, Leptæna euglypha, Pentamerus Knightii, Goniophora cymbæformis. Turritella gregarea. Gomphoceras pyriforme, Homalonotus Knightii, Serpulites longissimus, Trachyderma squamosa.

We have now passed through the Lower Palæozoic series. Before entering another great division of the old strata, it may be well to call attention to a few main points in their history. First, it may be observed that they are all of marine origin; hitherto no freshwater remains, one land-plant, no land animals, have been

found in the series. Secondly, the forms of life, viewed on a large scale, at first extremely few and rare, become more numerous as we ascend, and appear specially plentiful and varied in the parallel of Bala and Llandeilo, and in that of Wenlock and Dudley; the lower development constituting the grand Cambro-Silurian type, the upper one being truly and exclusively Silurian: very strong analogies, however, unite these groups into one great series of life. Thirdly, vertebral life appears in the upper part of the Silurians. Looking at the whole series of rocks, we remark above the micaceous systems which rest on the granitic skeleton, a vast thickness of sediments, mostly tinted by protoxide of iron, some deposited in tranquillity, others with local disturbance; alternately with these, thick aggregates of limestone, the fruit of chemical reagencies and vital secretions in sea-water; and bands of porphyry and greenstone, which were poured from submarine volcanic vents, and spread out on the old sea-bed. (Snowdonia, Sca fell, &c.) In conformity with this indication of the extensive effects of internal heat, we find the metamorphism of the slaty rocks, and the general induration of the entire series,—qualities which are, on the whole, reduced as we ascend in the strata.

During the deposition of these rocks some cases of nonconformity appear, as pointed out by the geological survey of Wales, between the Wenlock

shale and Caradoc beds, and between the fossiliferous groups of Bala and the almost azoic strata below. After the completion of the whole series, more general movements happened, especially in the districts of the English lakes, the Isle of Man, and the South of Scotland. For here the Silurian sea-bed was elevated into mountainous ranges; land was apparent; its shores were worn by the breakers; valleys were formed in it, and in these valleys, at a later time, were deposited the red sandstones and marls of the next great group of strata, to which we at once proceed.

MIDDLE PALÆOZOIC STRATA.

Which have only taken this name in the scale of English rocks, since the investigations of Lonsdale, and the field-work of Murchison, Sedgwick, and others, have demonstrated in Devonshire the true place of a large series of slaty, sandy, conglomeritic, and calcareous rocks, locally rich in fossils, to be, in a general sense, the same as that of the old red sandstone. Entirely different physical conditions must have accompanied the formation of these two very different types — the Devonian being by far the most developed, representing, probably, *a longer series of geological time*, and presenting no small amount of analogies, on the one hand, to the Silurians below, and on the

other, still stronger relationship to the mountain limestone, with which its strata are usually conformed, and to which it was formerly joined by Conybeare.

The old *Red Sandstone* type may be first noticed.

Thickness. Three to eight thousand feet.

Mineral Character. Beds of sandstone, conglomerate, clay, and concretionary limestone called "Cornstone;" of various colours, but mostly red. They are subject to slaty cleavage in the South of Ireland, and South Wales.

Subdivisions. Along the course of the Wye, the Usk, and the Towy, where this formation is most fully developed, it is composed of a triple series:

Upper. Quartzose comglomerates and sandstones.

Middle. Coloured marls and concretionary limestones.

Lower. Tilestone or flagstone series, with coloured marls, cornstones, &c. (We omit the fossiliferous tilestones at the base, for they are Silurian.)

The limestones of this series are less known in the North of England and in Scotland. Around the Cumbrian, Lammermuir, and Grampian mountains red conglomerates abound, and contain fragments of the neighbouring older rocks.

Localities. The Kymin Hill, near Monmouth; the Vans of Brecknock and Radnor; Kirby Lonsdale; south-east border of the Grampians.

Organic Remains. In the lowest beds round Woolhope Forest and May Hill some traces of land plants occurred to the author.* Animal remains are nowhere numerous in England; but at Gamrie, and some other localities in Morayshire and Cromarty, and in Caithness and the Orkneys, in gray beds, fishes of singular forms — Cephalaspis, Pterichthys, Coccosteus, &c. — have been described by Agassiz, Miller†, and others; and Mantell has recorded a Lacertian animal, Telerpeton Elginense, from the same quarter.‡ Some *bivalve shells* are mentioned by Miller. Only a few of these fishes have been found in Herefordshire and Caermarthenshire by Murchison.

In strong contrast with this peroxidated group and poor fauna, is the next or *Devonian type.*

In North Devon, De la Beche describes a series several thousand feet thick, of several distinct members, mostly subject to slaty cleavage, which lie as under, dipping mostly to the south.

Upper or Pilton Group. Slaty and flaggy beds, yielding land plants; and slaty and calca-

* Mem. Geol. Survey, vol. ii. pt. i. See also Strickland, in Geol. Proceedings, 1852.

† The Old Red Sandstone. ‡ Geol. Proceedings, 1852.

reous beds, yielding abundance of marine shells, corals, trilobites, &c.

Morthoe Group. Fine gray or green slates, with red and variously coloured sandstones,—neither fossiliferous.

Ilfracombe Group. Gray argillaceous slates and limestone bands, with some plants, several corals, and a few Brachiopoda.

Martinhoe Group. Red, brown, gray, and claret-coloured grits and slates, without fossils.

Linton Group. Gray slaty rocks, perhaps 1000 feet thick; in most parts rich in corals and Brachiopoda, and containing a few Gasteropoda and Cephalopoda.

Lowest, or Foreland Group. Red and gray grit rocks, without fossils.

In South Devon the series is of great thickness, and may be observed near Plymouth, with a great southward dip, as under.

Upper group of Boveysand Bay. Blue and gray shales, with thin calcareous bands, partly fossiliferous.

Red and gray grits and purple schists, with fossils in bands, with ironstone layers and quartz laminæ, crumpled by cleavage.

Carbonaceous and gritty beds, and schists with fossils, and some nodules of limestone.

Blue and gray schists, and nodular limestones, with layers of fossils.

Laminated schists, and layers of "ash," or trappean fragments.

The Plymouth limestone, — a thick but very variable mass, so rich in corals of the greatest beauty, as to be almost a reef. Many Brachiopoda, some Gasteropoda and Cephalopoda.

Lower group—thick purple slaty rocks, without fossils.

Organic Remains. In these Devonian groups we have *land plants* in and above the limestone of Ilfracombe; Polyparia in the gray parts of nearly the whole series, and specially abundant in the Plymouth limestones; their affinity to the Silurian life is indicated by Heliopora pyriformis, Cyathophyllum cæspitosum, Favosites Gottlàndica.

The *Crinoidea*, which occur in the same limestone, and in higher beds, belong to Platycrinus, Pentremites, Cyathocrinus, Actinocrinus, &c., and are more allied to the forms of the mountain limestone.

The *Brachiopoda* are numerous, and, for the most part, peculiar; but a rather considerable proportion of those in the upper part are the same as, or very similar to, Upper Palæozoic races.

The *Lamellifera* are few, including Cucullææ, Modiolæ, Pterineæ, Pleurorhynchi.

The *Gasteropoda* are numerous, more similar

on the whole to Upper than Lower Palæozoic forms; and the same is the case with the *Cephalopoda.** The Crustacea are all trilobites. *Fishes* are rare in the Devonian type of these middle Palæozoic strata, except in Russia, where Murchison had the good fortune to *find together* the *Devonian shells* and the *old red fishes.*

The Devonian type has been studied by several geologists on the Rhine and Moselle (Nieder Lahnstein), in the region of the Meuse, by Dumont, in the Boulonnais by Austen, Forbes, and Sharpe. In Ireland the peculiar characters of the series have been exhibited by Griffith.

Characteristic Fossils. Calceola sandalina, Leptæna nodulosa. Cyrtoceras sexdecimale. Brontes flabellifer. Holoptychius nobilissimus. Coccosteus. Pterichthys, &c.

We now pass, by an easy gradation, to the

UPPER PALÆOZOIC STRATA.

CARBONIFEROUS OR MOUNTAIN LIMESTONE.

Thickness. In the North of England 1500 to 2500 feet.

Mineral Character. Beds of limestone, chert, sandstone, shale, and coal; layers of ironstone nodules.

The limestones are nearly white, yellowish, gray, blue, or black; compact, oolitic, crystalline,

* Palæozoic Fossils of Devon and Cornwall, 1841.

or crinoidal: the chert black, or light-coloured: the sandstones coarse and even pebbly, or fine-grained, in thick beds, or thin laminæ, often micaceous: the shales mostly dark-coloured, fissile, and bituminous. The coal is generally sulphureous, and of inferior quality. It occurs only where the sandstones and shales abound; where the strata are principally calcareous, it vanishes from the series.

The general section consists, in Northumberland, of alternations of all the above; in Derbyshire the base of the formation is almost wholly calcareous and the upper part principally argillaceous. The method of variation from the northern to the southern type in Yorkshire, as recognised by Prof. Sedgwick and the author, is represented in the following table, which includes the millstone grit as a transition group above, and calciferous shales in a similar character below.

Northumberland and North-western borders of Yorkshire.	Ingleborough and Penyghent.	South-western border of Yorkshire and Derbyshire.
a. Millstone grit.	*Millstone grit.*	*Millstone grit.*
b. Yoredale shales, gritstones, coal, and five or more limestones.	Craven shale with some gritstone, and two or more limestones.	"Limestone shale" with some gritstones and argillaceous limestones.
c. Divided "scar limestones," with shales, gritstones, and coal.	Undivided "scar limestones."	Great mass of Derbyshire limestone.
d. alternations of limestone, gritstone, and shale, often reddened.	*Hardly any traces known.*	*of equivalent beds.*

In Flintshire the series, though less complete, appears to be analogous to that of the North of England; the section on the Avon at Clifton, one of the most complete in the South of England, offers above and below the great mass of undivided limestone (*c*) alternations comparable to the groups (*b*) and (*d*). The group (*d*) is finely developed, with Devonian affinities, in the eastern part of Milford Haven, and at Hook Point near Waterford. In Kulkeagh near Enniskillen the millstone grit (*a*) and great shale (*b*) correspond closely with the Derbyshire section, while below the great calcareous masses occur alternating grits and limestones (*d*). The black limestones of Barnstable in Devon strongly resemble, in mineral character, those which lie at the base of the Craven and Derbyshire shale.

Typical Localities. The mountains near Cross Fell, Ingleborough, Pendle Hill, Peak of Derby, Dean Forest, north side of the coal-field of South Wales, the Avon at Clifton, Mendip, Tenby, Milford Haven.

Organic Remains. Coniferous trees, Ferns, Stigmaria and other *land plants* in the sandstones and shales, and near the beds of coal. In Derbyshire marine plants in the limestone.

Polyparia abound — as Fenestella, Millepora, Cyathophyllum, Chætites, Syringopora, Amplexus.

Crinoidea are plentiful, as Pentremites, Platy-

crinus, Cyathocrinus, Poteriocrinus, Actinocrinus, &c.

Echinida rare, as Palechinus.

Brachiopoda very numerous, as Terebratula, Strophomena, Orthis, Producta.

Lamellibranchiata of several genera, as Modiola, Arca, Pleurorhynchus, Sanguinolaria, Solemya, Isocardia, Avicula, Pecten, (no Ostrea !) &c.

Gasteropoda plentiful — as Pleurotomaria, Macrocheilus, Loxonema, Murchisonia, Euomphalus, Cirrus, &c.

Pteropoda, as Conularia.

Heteropoda, as Bellerophon.

Cephalopoda, as Nautilus, Clymenia, Goniatites, Orthoceras, Cyrtoceras.

Crustacea, Trilobites, as Phillipsia, Griffithsia.

Fishes numerous: teeth, and dermal spines of cartilaginous mostly heterocercal fishes — Megalichthys —Holoptychius — Psammodus, Helodus, Orodus, &c.

Reptiles or other vertebrata not yet recognised.

Characteristic Fossils. A large proportion of the whole marine series. Syringopora geniculata, Amplexus Sowerbii, Platycrinus tuberculatus, Poteriocrinus crassus, Actinocrinus Gilbertsoni—Orthis resupinata, Producta gigantea, Pleurorhynchus hibernicus, Euomphalus catillus, Bellerophon costatus, Goniatites sphæricus, Phillipsia ornata.

MILLSTONE GRIT GROUP.

Thickness. Under 1000 feet.

Above the limestone series of Northumberland, Durham, Yorkshire, Derbyshire, and Lancashire, rests a thick mass of gritstones and shales, *characterised* by the prevalence of one, two, or three rocks of coarse gritstone, partially filled with rolled fragments of quartz and felspar. Occasionally garnets and other minerals, also in rolled pieces, present themselves. In this series beds of coal occur, and, though of bad quality, are worked to a considerable extent in the moorland districts of Yorkshire and Lancashire. Thin limestones, chert beds, ironstone nodules, beds of excellent flagstone, and abundance of shales, are found in the same districts.

In Derbyshire the millstone grit is a very important, but less varied series than that above noticed. Under the coal-fields of the midland counties it is less distinctly traced; in those of Gloucestershire, Somersetshire, and South Wales, it is supposed to be represented by red cherty or pebbly gritstones, called Farewell Rock.

The organic remains of the millstone grit group are most abundant in the North of England. Terrestrial plants, for the most part identical with those of the coal formation above, lie in the gritstones. Ferns are not common, but Sigillariæ, Calamites, Annulariæ, &c., are not infrequent.

Marine Zoophyta, Conchifera, Mollusca, &c., mostly identical with those of the mountain limestone beneath, lie in the thin limestones, cherty sandstones, and certain shales and ironstones.

COAL FORMATION.

Thickness. From 1000 to 11,000 feet.

Strata of sandstone, shale, clay, coal, and, very rarely, limestone; layers of ironstone nodules, admixtures of pyrites. The sandstones are generally micaceous, and either very coarse, or fine-grained, in thick beds, or thinly laminated, often alternating with the shales. These are generally dark and bituminous, sometimes black, laminated in various degrees: some of the clays are white.

The *general section* consists of a vast number of repeated alternations of sandstone, shale, coal, and ironstone. The several parts of the series are not easily distinguishable, except for small tracts of country; the coals and ironstones are the most regular strata. Of the former, in some cases, are forty or fifty seams or beds, from less than an inch to more than a fathom in thickness. In a few places, the coming together of several seams makes one enormously thick bed of coal, as in Staffordshire and Ayrshire. A peculiar bed of shelly limestone occurs in the upper part of the coal-fields of Shropshire and Manchester; and a *marine* conchiferous layer in the lower part of the Yorkshire coal-field.

Localities. The coal formation is generally found in limited patches, sometimes correctly called basins. The principal are those of the Forth and Clyde, Newcastle, Durham, Cumberland, Yorkshire, Derbyshire, Nottingham, Lancashire, Ashby in Leicestershire, Coventry, Dudley, Shropshire, North Wales, South Wales, Kingswood in Gloucestershire, Somersetshire. Almost all the central counties of Ireland. France: near Boulogne, Mons, St. Etienne. Belgium: Namur, Liege. Germany: near Elberfeld, Bingen, Silesia, Moravia, Poland, the Carpathians.

Organic Remains. Abundance of *land Plants*, as Ferns, Calamites, Lepidodendra, Sigillariæ, &c. (Stigmariæ are the roots of the preceding); no Zoophyta; no Radiaria; Conchifera, marine or estuary, or fluviatile, according to the district; Productæ, Terebratulæ, Nautili, &c., in the series of Coalbrook Dale, Megalichthys, Palæoniscus, Holoptychius, and other scaly Fishes; *in a particular bed* in Yorkshire occur *Goniatites Listeri*, Orthoceras, *Pecten papyraceus*, and Fishes.

Coal is nothing else than a compressed and chemically altered mass of vegetables. The tissue of some of the trees remains in the substance, and may be detected by fracture, burning, and thin sections. In some cases trees appear rooted in attitude of growth, their stems above, their roots

in or below the coal. The accumulation of coal in so many parallel beds can be explained by no hypothesis, unless it includes gradual and long continued subsidence of limited tracts of the old sea-bed and the adjoining lands.

PERMIAN SYSTEM.

Under this title Murchison, in 1844, classed the magnesian limestone series of England, and a portion of the sandstones of the superincumbent new red (Bunter).

In the government or ancient kingdom of Perm, the series is much expanded and more complicated than in England.* The lowest member in the north of England is

The LOWER NEW RED (Rotheliegende), called "Pontefract Rock" by Smith (1821).

Thickness. Seldom exceeding 100 feet in the north of England.

Mineral Character. Red, yellow, and purple sandstones, sometimes conglomeritic, sometimes mixed with red sandy or argillaceous shales.

Localities. It ranges on the west of the terrace of magnesian limestone, from Newcastle to Nottingham, and rests unconformably on the coal. Near Pontefract, in Yorkshire.

Organic Remains. Only plants have yet been

* Murchison, Geol. of Russia.

seen in these sandstones; they resemble generally those of the coal formation, but are seldom in a perfect state. The same remark applies to Germany.

MAGNESIAN LIMESTONE.

Thickness. Seldom exceeding 300 feet in the north of England.

Mineral Character. Composed of limestones, clays, and gypsum. The limestones, which compose the greater part of this formation, are very variable in all respects; white, yellow, reddish, gray, purple; compact, powdery, oolitic, crystalline, with strings and nests of calc spar; highly magnesian, or purely calcareous. The clays are red, white, often gypseous.

Subdivisions.

England.	Germany.
a. Gray laminated limestone, with little magnesia and very few fossils.	*a.* Stinkstein, Rauchwacke.
b. Red and white clay and gypsum.	*b.* Coloured marls.
c. Yellow magnesian limestone.	*c.* Zechstein.
d. Marl slate.	*d.* Kupferschiefer.

Forms a remarkable range of low hills, resting like a terrace on the carboniferous formations of the North of England, in a line from the Tyne to the Trent; and on the southern border of the Lancashire coal-field. Conglomeritic beds nearly

coeval occur in Craven, Westmoreland, and Cumberland. When the calcareous beds are absent, the Rotheliegende and Lower Bunter may be undistinguishable.

Typical Localities. Sunderland, Ferrybridge, Doncaster, Mansfield. The Thuringerwald, Mansfeldt.

Organic Remains. In England very few, *increasing in number northward* from Nottingham to Sunderland: near Manchester several species occur in variegated marls, associated with thin limestones. In Durham a few plants; Crinoidea; several Brachiopoda, and other Conchifera; few Gasteropoda and Cephalopoda; several fishes. The series of fossils is richer in Germany and Perm.

Characteristic Fossils. Among shells, *Axinus obscurus, Producta calva;* among fishes, *Palæoniscus Freiesleben* and other species of that remarkable genus.

LOWER BUNTER.

Whether any portion of the "New Red Sandstone" of England should be classed with this member of the Permian system, I cannot positively affirm. The "Haffield Conglomerate," described in my work on the Malvern Hills *, lies below all that is regularly classed as New Red Conglome-

* Memoirs of the Geological Survey, vol. ii.

rate, and probably is a Permian rock. It contains no organic exuviæ.

Looking back on the long series of Palæozoic stratifications, we find some facts established which are of primary importance in the physical history of the earth.

This series of rocks composes by far the greatest part of the thickness of the crust of the earth, as may be in some degree illustrated by the sectional diagram which accompanies the map.

Previous to their formation granitic, and during their deposition other igneous, compounds were formed, and in the latter case effused on the old sea bed of the time. (Snowdonia.)

There were displacements of the old sea bed during the Palæozoic period, especially after the deposition and *consolidation* of the Lower Palæozoics, so that later strata cover unconformably the earlier displaced formations. (Westmoreland.)

In the case just mentioned, and others, in Scotland, the Lower Palæozoic rocks had been uplifted from the sea; washed and worn away by its waves; so that on the worn surface the later palæozoics are deposited. The shores of the sea thus become partially known: and from other phenomena we infer valleys, descending into arms of the sea, from ranges of mountainous land, from land which is still mountainous. Thus some of the grand features of physical geography were

fixed in the early periods now under consideration, and some of the ranges of mountains may be justly called "palæozoic."

Previous to the close of this system, after the deposition of the coal, a great disturbance happened by which the sea bed was broken up, and the land in many places thrown into new forms.

Of the marine life of the Palæozoic ages we have abundant remains, which upon the whole grow more varied as we ascend. In the earliest period as yet only Brachiopoda and Crustacea; till the close of the Lower Palæozoic ages no fishes have been found; at the same point of time we discover traces of land plants. In the later part of the Palæozoic period land plants abound, and may be seen erect as they were growing; fresh waters and estuaries contribute to the catalogue of life; fishes are numerous; and reptiles have left a few traces. But as a whole this is the age of Trilobites and Orthoceratites. From the land plants and marine corals, equally, we infer that a higher temperature prevailed generally over the northern zones, during the Palæozoic ages, than can be accounted for by any variations in the arrangement of sea and land, or any fluctuations in the other surface elements of climate.

It has been conjectured that the atmosphere was then more loaded with carbonic acid; a condition which Brongniart thought favourable, and

Daubeny has proved to be at least not unfavourable, to the growth of ferns and other cryptogamic plants, which make up so large a part of the Palæozoic flora of the world.

MESOZOIC STRATA.

These contain less ancient forms of life, and almost everywhere in Europe rest unconformably on the Palæozoic or older rocks. The lower part has been generally called

NEW RED SANDSTONE,

(SYN. *Grès bigarré*, Fr.; *Bunter Sandstein*, Ger.)

Thickness. Seldom exceeding 1000 feet.

Mineral Character. Sandstones and conglomerates of a red, white, or greenish colour; in the upper part mixed with red and greenish marls, the lower part often admitting accumulations of pebbles, sometimes cemented into a conglomerate. Oblique lamination (indications of sea currents) common.

Upper. White and red sandstones and red marls (Malvern). White sandstones (near Boroughbridge).

Lower. Red and white sandstones and conglomerates (Nottingham).

Organic Remains rare. In England, some trace of plants, as Calamites; the Labyrinthodon, Cladyodon, and Rhynchosaurus, of Warwickshire. In

Scotland, Labyrinthodon and Turtle. In Germany, the Bunter contains Voltziæ and other plants. *No Belemnites or Ammonites.*

Localities. Much of the centre of England, in broad undulated plains; from the Tees to the Exe, and from Leamington to Liverpool.

NEW RED MARLS.

(Syn. *Marnes irisées, Calcaire conchylien*, Fr.; *Keuper, Muschelkalk*, Ger.)

Mineral Character. Clays, with some sandstones of red, greenish, and gray tints. In Germany limestone beds (Muschelkalk) occur. Salt and gypsum lie in several parts of the series in England and Germany.

Subdivisions.

England.	Germany.
a. Variegated marls * (salt).	*a.* Variegated marls (salt).
b. Sandstone (Keuper).	*b.* Keuper Sandstones.
c. Variegated marls, magnesian bands, &c.	*c.* Marls.
d. Magnesian conglomerates (south of Bath).	*d.* Muschelkalk (salt).
	e. Marls.

Organic Remains. In England the Keuper contains, near Malvern, fish teeth, and fin bones,

* The uppermost band of these marls, usually greenish white, may be mistaken for a Lias clay, but is of a *different structure.* The blue marls which accompany Keuper sandstones, near Malvern, are more like the Lias, and contain a shell which occurs also in the bone beds.

fossil wood, and a few shells, and the marls *c*, a few peculiar plants.

The Magnesian conglomerate of Durdham Down, near Bristol, appears to be of this age. It contains Thecodont Saurians.

In Germany, the Keuper contains plants (Pterophyllum), shells, Chelonida, Saurians. The Muschelkalk contains Encrinites, especially *E. moniliformis*; shells, especially *Ceratites nodosus* and *Avicula socialis*, and Saurians, but no Belemnites.

MIDDLE MESOZOIC STRATA.

In the formations which constitute these strata, probably 2000 species of fossils are known. Many of these are common to two or more formations, but few or none occur in the cretaceous system. Nearly half the species belong to genera supposed to be extinct. All the fishes and reptiles belong to extinct genera.

LIAS FORMATION.

Thickness. In Yorkshire, about 1000 feet.

Description. Consists principally of laminated blue clay, or shale, with much pyrites, some bitumen, ironstone courses, and septaria. In it are beds of sandstone and sandy limestone, and strata of blue and white limestone.

Subdivisions. *a.* Upper lias shale of Yorkshire.

b. Ironstone and marlstone.

c. Middle lias shale of Yorkshire.

d. Lias limestones, blue and white.

e. Lower lias marls, with bone bed.

Physical Geography and Localities. A characteristic feature of English geology, running in a long, connected course of hill slopes and low plains beneath the escarpment of the lower oolites, from the Tees to the Exe. Through a great part of this course it has tempted trials for coal. Insular hills of oolite rest upon and diversify it. It occurs in the Hebrides, the east and centre of France, Switzerland, and Germany.

May be well studied on the Yorkshire coast; Grantham, Belvoir, Rugby, Cheltenham, Bath, Lyme Regis; beneath the basalt of Antrim. The lias limestones are well seen at Barrow-on-Soar, near Shipston, near Bath, and at Lyme Regis.

Organic Remains. Plants. Marine plants in some beds; some plants drifted from the land, as coniferous wood — sometimes turned to jet — Otopteris, &c.

Polyparia and Echinida rare in these argillaceous beds.

Crinoidea, especially Pentacrinites and Stellerida, as Ophiura, frequent.

Brachiopoda, especially Terebratula and Lingula, frequent.

Conchifera numerous and of many genera, as

Ostrea, Pecten, Lima, Plagiostoma, Cardium, Corbis, Pachyodon, Astarte, Pholadomya.

Gasteropoda not numerous—Trochus anglicus.

Cephalopoda plentiful. Ammonites and Belemnites very numerous — Onychoteuthis, Nautilus, Loligo. *Annulosa*, as Serpula.

Macrourous Crustacea, as Glyphia.

Insecta. Mr. Brodie found at Westbury, in the lower part, above the bone bed, Coleoptera, Neuroptera, &c., and a repetition of insect forms in the upper part of the lias at Dumbleton.

Fishes. Numerous. Tetragonolepis, Dapedius, Pholidophorus.

Reptiles. Ichthyosaurus, Plesiosaurus, Teleosaurus, Pterodactylus.

Characteristic Fossils. Pentacrinus Briareus, Gryphæa incurva, Plagiostoma giganteum, Trochus anglicus, Belemnites paxillosus, Ammonites Bucklandi, Dapedius politus, Ichthyosaurus communis, Plesiosaurus dolichodeirus, &c.

LOWER OR BATH OOLITE FORMATION.

(Syn. *Lower part of the Jura Kalk*, Ger.)

Thickness. Near Bath, 400 feet; in Yorkshire, 800 feet.

Mineral Character. White, yellow, or ferruginous oolite, and compact and shelly limestone, variously associated with sands, slaty sandstones, clays, and marls.

Subdivisions. Near Bath, according to Lonsdale.

a. Cornbrash, coarse limestone.
b. Forest marble group, composed of coarse shelly oolite, imbedded in sands, nodular sandstones, and clay.
c. Great oolite.
d. Fullers' earth, clays, marls, and limestone.
e. Inferior oolite.
f. Sand.

In Yorkshire we have a different series.

a. Cornbrash, shelly, sometimes ferruginous.
b. Sandstones, shales, coal, and plants.
c. Slaty, calcareous, shelly sandstone beds.
d. Oolite, shelly, sometimes rich in iron.
e. Sandstone shale, coal, and plants.
f. Ferruginous sands, shelly.

Physical Geography and Localities. Forms ranges of dry hills, which overlook the upper and middle oolite hills, surpassing generally the altitude of the chalk, and commanding extensive views over the older formations. Yorkshire, Lincolnshire, Northamptonshire, Rutland, Oxfordshire, Gloucestershire, Wilts, Somerset, Dorset.

Types. The Bath series, more or less complete, is observed in all the southern parts of the range. Bath, Cheltenham. The Yorkshire series may be studied near Scarborough and Whitby; it has been recognised by Murchison at Brora, in Sutherland, and by Morris in Lincolnshire. Foreign localities generally resemble the Bath series: Normandy, the Jura, Savoy, Franconia, &c.

Organic Remains. Plants, mostly of terrestrial growth, as coniferous wood, lycopodia, equiseta, ferns, zamiæ. These are most plentiful near Scarborough and Whitby, and at Stonesfield and Collyweston, in littoral, estuary, or freshwater deposits.

Polyparia plentiful, especially spongiform, milleporiform, and madreporiform. The latter sometimes accumulated like reefs.

Crinoidea, as Apiocrinus and Pentacrinus.

Echinida numerous, as Clypeus, Clypeaster, Cidaris, Diadema, Galerites.

Stellerida, both as Ophiuridæ, and Asteriadæ.

Brachiopoda numerous, both smooth and plaited.

Conchifera abundant, as Ostrea, Pecten, Lima, Plagiostoma, Pinna, Avicula, Cardium, Trigonia, Lutraria, Panopæa, Arca, Cucullæa, Venus, Astarte.

Gasteropoda. Melania, Nerinæa, Natica, Nerita, Trochus, Turbo, Voluta, Conus, &c.

Cephalopoda, especially Ammonites and Belemnites, of which the species are numerous and characteristic.

Annulosa, as Serpula.

Crustacea, mostly analogous to Astacus.

Insecta. Coleoptera, Neuroptera, &c.

Fishes. Teeth and detached parts of Acrodus, Gyrodus, &c.

Reptiles. Cetiosaurus, Steneosaurus, Megalosaurus, Ichthyosaurus, Pterodactylus, Turtle.

Mammalia. The oldest known in Britain occur at Stonesfield, Oxon, of two genera; Amphitherium and Phascolotherium.

Characteristic Fossils. Equisetum columnare, Pterophyllum pecten, Apiocrinus rotundus, Terebratula maxillata, Trigonia striata, Pholadomya acuticosta, Belemnites giganteus, Ammonites Blagdeni, &c.

MIDDLE OR CORALLINE OOLITE FORMATION.

(SYN. *Middle part of the Jura Kalk,* Ger.)

Thickness, in Yorkshire, 300; in Oxfordshire, 600 to 800 feet.

Mineral Character. Blue or yellow oolite, occasionally of a pisolitic character, locally full of coral; enclosed in a mass of cherty or calcareous shelly sandstones; resting on a thick blue clay and shelly sandstone.

Subdivisions. *a.* Upper calcareous grit.
b. Coralline oolite.
c. Lower calcareous grit.
d. Oxford clay.
e. Kelloways rock.

Physical Geography and Localities. Forms a range of dry hills of moderate elevation in England.

Types. Near Scarborough, Oxford, Calne, Weymouth.

Organic Remains. Land plants, as coniferous wood, and fruits of Palmaceæ, occur at Malton.

Polyparia abound, so as even to make reef-like masses. The genera are mostly identical with those of the lower oolites.

Crinoidea occur.

Echinida are plentiful and beautiful, especially Cidaris, Clypeus, Nucleolites, &c.

Asteriadæ are less frequent.

Brachiopoda, common.

Lamellibranchiata, abundant.

Monomyaria, as Gryphæa, Pecten, Plagiostoma.

Dimyaria, as Trigonia, Cucullæa, &c.

Gasteropoda, as Melania, Nerinæa, Natica, Turbo, &c.

Cephalopoda, especially Belemnites, Ammonites.

Crustacea, as Glyphia.

Fishes, not common.

Reptilia include Megalosaurus and Pliosaurus.

Characteristic Fossils. Astræa tubulifera, Cidaris intermedia, Nucleolites dimidiatus, Plagiostoma rigidum, Gryphæa dilatata, Ammonites Calloviensis, Belemnites tornatilis.

UPPER, OR PORTLAND OOLITE FORMATION.

(Syn. *Epioolite*, Brongn. *Upper part of the Jura Kalk*, Ger.)

Thickness. 200 to 600 or 800 feet.

Mineral Character. A mass of limestone, partly oolitic, partly compact or cretaceous, including nodules and ramifications of chert; green sandy and nodular beds below, resting on a thick blue clay, with lignite and layers of Septaria.

Subdivisions.

a. Portland oolitic rock, with sands.

b. Kimmeridge clay.

Localities. Isle of Portland, Tisbury in Wilts, Swindon, Garsington, Brill, Aylesbury.

Organic Remains. Stems of land plants allied to Cycas and Zamia, are found in attitude of growth in Portland.

Polyparia and *Echinodermata*, rare.

Brachiopoda, not frequent.

Conchifera, of considerable size; as Cardium, Ostrea, Pecten, Trigonia, mostly of species different from those in other strata.

Gasteropoda, as Trochus of large size.

Cephalopoda, chiefly Ammonites, often of great

magnitude in the Portland Rock, and Belemnites in the Kimmeridge Clay, with Ostrea deltoidea.

Characteristic Fossils. The Cycadiform plants, Cardium dissimile, Astarte cuneata, Trigonia gibbosa, Pecten lamellosus, Ammonites biplex.

WEALDEN FORMATION.

Mineral Character. Variously coloured sands and clays, with interspersed lignites, conglomerates, and calcareous portions in the former, and limestone and ironstone in the latter. The organic remains indicate that it was principally a freshwater and estuary deposit.

Subdivisions.

a. Weald clay, alternating below with

b. Hastings sands, which rest on

c. Purbeck, or Lower Wealden clays.

Physical Geography and Localities. It is almost peculiar to the Weald of Kent and Sussex, the Isle of Wight, and Purbeck, though traces occur in the Vale of Wardour (Wilts), on Shotover Hill, and at Beauvais in France. In Sussex the middle sands rise to 805 feet, enveloped by a valley of the Weald clay in an oval ring.

Organic Remains. Wood belonging to the Monocotyledonous division of plants, Gyrogonites, Ferns; Cyprides, Cyclades, Unionidæ, Physæ, Limnææ, Paludinæ (none of the marine tribes of Polyparia, Echinida, Brachiopoda, or Cephalo-

poda). Insects have been found by Brodie in the Vale of Wardour. Fishes of the genus Lepidotus; Iguanodon, Hylæosaurus. Turtles.

According to late researches by Professor E. Forbes, the Purbeck beds contain several layers of alternating lacustrine and estuary or submarine deposits. The lacustrine shells and Gyrogonites are so extremely similar to tertiary and living species, as to be scarcely distinguishable.

UPPER MESOZOIC STRATA.

They rest unconformably on the oolitic formations, or on the lias, in Yorkshire and Dorsetshire, the oolitiferous sea-bed having been previously displaced very extensively.

GREENSAND FORMATION.

(Syn. *Glauconie*, Fr.; *Quadersandstein of Pirna*, Ger.)

Mineral Character. A stratified mass of sands, occasionally pebbly, often cherty, almost always slightly calcareous, and characterised by abundance of green grains in some or all of the beds. In many tracts, the lower sands are very irony and yield ochre. In the midst of the series is a sandy and calcareous fossiliferous clay (Gault).

Subdivisions.

a. Upper greensand, passing below into
b. Gault, which sometimes alternates with

c. Lower green or iron-sand, enclosing limestone in Kent, and fullers' earth at Nutfield in Surrey.

Physical Geography and Localities. In England, generally forms the base of the chalk hills, but in Blackdown and the Weald of Surrey and Kent, rises into separate ranges of hills. In the north-east of Ireland, covered by basalt. On the Continent, extends with the chalk, and is found separate from that rock in Saxony, along the Alps, Carpathians, &c.

Types. Isle of Wight, and the country near Petersfield, for the whole series; upper greensand in Wiltshire; gault at Folkstone and Cambridge; lower greensand in Kent and Surrey.

Organic Remains, very numerous. *Marine plants.*

Amorphozoa, or sponges, frequent, and of varied forms, as Siphonia.

Polyparia, of small size and delicate beauty.

Echinida very numerous, of many genera, mostly small and delicately sculptured.

Stellerida occur.

Crinoidea, rare.

Brachiopoda, beautiful, several groups of Terebratula.

Monomyaria frequent, including beautiful Pectinidæ, Limæ, &c.

Dimyaria, rich in Arca, Cucullæa, Venus, Thetis, Cardium, Trigoniæ, &c.

Gasteropoda, numerous; among them Zoophagous tribes, as *Rostellaria*.

Cephalopoda, represented by many Ammonites, Hamites, Crioceratites, and a few small Belemnites.

Crustacea, chiefly of the macrourous decapods.

Annulosa, several species.

Fishes and reptiles indicated chiefly by teeth.

Characteristic Fossils. Siphoniæ, Turbinolia Kœnigi, Galerites subuculus, Terebratula biplicata, Exogyra sinuata, Pecten quinquecostatus, Inoceramus sulcatus, Trigonia aliformis, Cardium Hillanum, Ammonites splendens, Belemnites minimus, Hamites intermedius.

CHALK FORMATION.

(SYN. *Craie, craie tufau*, Fr.; *Kreide, Kreidemergel*, Ger.; *Scaglia*, It.)

Mineral Character. Consists principally of carbonate of lime in a finely granular state, (sometimes full of minute Foraminifera and Entomostraca,) imperfectly indurated, and white. The stratification is rendered evident chiefly by layers of flint nodules, which occur at regular intervals mostly in the upper part, but sometimes in other parts, or through nearly the whole of the mass.

Subdivisions. *a.* Upper chalk.
b. Lower chalk.

c. Chalk marl. Red chalk is at the base of the Yorkshire series.

Physical Geography. Occupies generally a district of connected green (not woody) hills, with dry valleys; very strong springs at their base; surface excavated in pits and grooves, and often covered with flints.

Localities. The Wolds of York and Lincoln, the Downs of Berks, Wilts, Dorset, Hants (Isle of Wight,) Sussex, Surrey, Kent. Foreign:— Round the tertiary basin of Paris, south-east of France, Belgium, Poland, Isle of Rugen.

Organic Remains very numerous, mostly marine, but including Cycadeæ and other *plants* drifted from the land.

Amorphozoa abundant, often enclosed in flint, which, likewise, as well as the chalk, contains *Foraminifera.*

Polyparia, less frequent.

Echinida, numerous; among them genera unknown in older strata, as Ananchytes, and others (Cidaris, &c.) of great beauty.

Stellerida, of several species.

Crinoidea, as Apiocrinus, Marsupites.

Brachiopoda, frequent.

Conchifera plentiful, including Gryphæa, Inoceramus, Plagiostoma, Spondylus, Pecten, &c.

Gasteropoda, less abundant.

Cephalopoda, including Ammonites, peculiar

groups of Belemnites, Scaphites, Turrilites, Baculites, &c.

Crustacea and *Annelida*, a few.

Fishes, many, including (in the chalk) forms approaching to existing tribes.

Reptiles, of large size, as Ichthyosaurus, Mosasaurus.

Characteristic Fossils. Marsupites ornatus, Ananchytes ovatus, Galerites albogalerus, Inoceramus Cuvieri, Plagiostoma spinosum, Terebratula plicatilis, Belemnites mucronatus, Mosasaurus Hoffmanni.

On a review of the Mesozoic strata, we find that, though they contain alternations of limestone, sandstone, clay, coal, ironstone, &c., these are generally distinguishable lithologically from the rocks bearing the same names in the Palæozoic series.

The forms of life, whether terrestrial, fluviatile, or marine, are in general very different; often referable to different genera, always distinct specifically, more numerous and more varied. This is the Age of Reptiles. Though in Yorkshire and Dorsetshire unconformity appears among these strata, by the over extension of the chalk and greensand, to the Lias, they have rarely been exposed to igneous action; and, except in the cases of the Whindyke in Yorkshire, and the Antrim Basalt, they have seldom suffered metamorphism.

At the close of this period, through great part of Europe, the sea-bed was again disturbed, new outlines were imparted to the land and sea, and very different conditions of life began.

The last great group of stratified deposits comprises the CAINOZOIC SERIES, in which lie the latest of the extinct races of plants and animals.

CAINOZOIC, OR TERTIARY STRATA.

(SYN. *Superior Order* of Conybeare. *Pleiocene, Meiocene, and Eocene Deposits* of Lyell. *Tertiärgebilde*, Ger. *Terrain de Sédiment supérieur*, Fr.)

Tertiary deposits, formed since the ocean became much divided into arms and gulfs, have so much of local character and independent origin, as to render it almost impossible, by direct comparisons of stratification, to refer these dissociated and interrupted strata to one general series. It is only by employing intermediate analogies, and the evidence of organic remains, that we can form to ourselves a proper general view of the order of antiquity of the deposits in different districts. On this account it is always best to describe the tertiary strata according to the natural regions in which they were formed: the English tertiaries are one series; the Parisian another, and very analogous one; the Subapennine a third; the

Danubian a fourth. There are many others in Europe, Asia, and America.

The notices in the text will be confined to the English tertiaries, for though these are, indeed, of small extent compared to the Cainozoic rocks which range parallel to the Alps and Apennines, the Caucasus and the Himalaya, they are highly instructive, and have been very carefully studied, so as to offer an excellent basis for wider inquiries. According to Deshayes and Lyell, the tertiary series of Europe may admit of being ranked in three leading groups, according to the numerical relation of the organic remains with existing species of shells. The upper group, with from 40 to 95 per cent. of living species (Pleiocene), includes, the Sicilian tertiaries, the crag, and Subapennine marls: the middle group, with about 20 per cent. (Meiocene), the tertiaries of the Danube, Rhine, Loire, and Garonne: the lower group, with about 5 per cent. (Eocene), is typified by the Calcaire grossier of France, the freshwater beds of Headen, the London clay, and the Plastic clays of England.

EOCENE, OR LOWER TERTIARY FORMATIONS.

The series fills the northern half of the Isle of Wight, and exhibits the following general terms, according to Prestwich and Forbes: —

Freshwater marls and estuary sands of Headen Hill and the northern parts of Isle of Wight. — Many alternations.

Barton clay, under yellow and white sands. It is a thick, dark, uniform clay with chloritic grains and many marine shells, 250 feet.

Bracklesham sands of a yellow tint, including layers of pebbles derived from chalk flints. With them lie variously coloured clays, sands, and lignite. 543 feet.

Bognor beds, consisting of sands, yellow, green, &c. 321 feet. Resting on blue clay with chloritic grains, 200 feet.

Plastic clay and sands of several colours, 100 feet.

The "London Clay" is coeval with the Bognor beds, and the sands, clays, and pebbles of Blackheath are the equivalents of the plastic clay. London clay and plastic clays spread to the north-east as far as Harwich.

Organic Remains. Those in the London clay, and in certain clays below, and in green sands which are near the base of the whole series, are for the most part marine, and consist of an immense number of shells, among which are the Univalves, Voluta, Rostellaria, Fusus, Cassidaria, Ancilla, Buccinum, and other existing genera: no Belemnites or Ammonites; very few Terebratulæ or Echinida. Species of these (5 per cent.) are

still in existence. Most of them are characteristic of the formation.

The Limneæ, Planorbes, and Gyrogonites, in the freshwater marls, are in some places associated with Palæotheria and Anoplotheria.

At Kyson, near Woodbridge, the London clay has yielded mammals (Macacus, Hyracotherium, and Didelphis).*

PREGLACIAL FORMATIONS.

These are in England referable to two groups of no great thickness or extent, and both confined to the low parts of England east of the chalk (Essex, Suffolk, Norfolk, Yorkshire). The upper portion *immediately* precedes in time the glacial deposits, and is chiefly of lacustrine character; the lower portion is littoral and marine.

* The calcaire grossier of the Paris basin corresponds in age to the London clay, and the subjacent coloured sands and clays to the plastic clay group of England.

The freshwater deposits in the Paris basin consist of upper and lower; the former characterised by silicious millstone, the lower composed of marls locally gypseous. In the gypsum lie bones of Palæotheria, Anoplotheria, Didelphis, and many other quadrupeds. The intermediate marine beds are chiefly sands. It is difficult to determine the relative age of the detached tertiary freshwater deposits in other parts of France, Germany, Hungary, &c. Some of them are of much more recent date.

Upper Part. The subterranean forests of East Norfolk, at Happisburgh, &c., which are covered by boulder clay. Elephants' bones, deer, &c., occur in it.

Lower Part. The "Mammaliferous" crag of Norfolk, with Littorina. Elephant's bones, deer, &c.

The "Red Crag" of Suffolk resembles almost exactly a shingle or pebble-beach, with layers of sand and shells, being composed of pebbles of various sorts, rolled and worn fish-teeth and bones, a few bones of extinct large quadrupeds, also worn; many shells, sometimes worn, sometimes not; parts of Crustacea, Polypifers, &c. The whole has an ochreous aspect, from the admixture of oxide of iron. At or near the base the bones, teeth, and phosphatic nodules are in sufficient quantity to be extracted for agriculture. Among the bones are those of Mastodon, Hippopotamus, Physeter, Cervus, but as yet no Palæotheria. Below it, "The Coralline Crag," seldom completely exposed, is lighter in colour and more uniform in composition, and appears to have been deposited with more tranquillity: it is a coralline limestone at Orford, and contains abundance of shells, *not at all worn*, and not ochraceous, at Ramsholt and other places. Bones are rarely found in it.

Organic Remains. These are very plentiful: there are about 500 species of Polypifera, Con-

chifera, and Mollusca in the crag. Of these, about 40 per cent., both from the upper and lower portions, are said by Deshayes to belong to species which still exist, mostly in the neighbouring seas. M. Agassiz states the fishes to be all of extinct species. *Fusus contrarius*, *Buccinum Dalei*, &c., are perhaps characteristic of the upper or red crag. Mr. S. Wood has given elaborate catalogues of the Invertebrata of the crag *; Owen has described some of the Mammalia †; Charlesworth divided the crag into three parts. The upper part ("Mammaliferous Crag") may be regarded as an estuary variety, not much different in time from the Red Crag, immediately preceding the Glacial Era in the sea, as the Happisburgh Forests preceded it on the land.

* Transactions of the Palæontographical Society.

† An. Nat. Hist. vol. iv.

CAVERN DEPOSITS.

There seems reason to think a great proportion of the ossiferous caves of Europe received their interesting contents in the preglacial period, and that several of the races therein buried became extinct in the northern zone, in consequence of the great physical change indicated by glacialism. Murchison regards the great Silurian region as feeding ground for the elephant and rhinoceros before the occurrence of the glacial crisis, which has left such unequivocal traces round the Baltic. The region no doubt was cold, and the hairy covering of the Pachyderms was adapted to it, but there is no reason to suppose it had the severely arctic character which belongs to it at present.

From various causes some of the caverns and fissures naturally existing in thick limestone rocks have been partially filled by a mass of materials holding bones of the above-mentioned and other races of animals. In some cases the animals are conjectured to have entered the caves for the mere purpose of dying in quiet (bear caves of Franconia); into others, hyænas have been the instruments of dragging the carcases of elephant, rhinoceros, deer, &c. (Kirkdale, Kent's Hole.) Grazing quadrupeds have fallen into others (Mendip caves, the ossiferous fissures of Nice, Gibraltar, &c.); and currents of water have con-

tributed to carry the bones into particular repositories, or to move them along the passages of a cave. The extent of the earth's surface over which ossiferous caves and fissures have been discovered is prodigious. In the North and South of England, in Ireland, South and South-east of France, the Ardennes, the Harz, Franconia, Wurtemburg, Switzerland, and along the Mediterranean shores and islands, are the most remarkable localities in Europe. Bone-caves occur in India, North America, South America, and Australia.

Upon the whole the animal remains are analogous in all these situations; but there is much local diversity. It is probable that they are nearly all of one geological period, contemporaneous with the fossil elephant, but posterior to the period when Palæotheria, and some other extinct genera of land animals, lived on some parts of the surface of Europe. No doubt into a cave full of old and extinct quadrupeds others in more modern times might enter, fall, or be driven to die; and thus a mixture of existing and extinct races be occasioned. Still more probable is the event of man, in an early and uncivilised state, or in a state of war and oppression, occupying a cave formerly tenanted by wild beasts, and there leaving traces of human art. Apparently this is the right view of most of the cases of human remains found mixed among, or buried in, or lying upon

the heaps of older bones. Some of the caves in the South of France and in Belgium, where human remains and rude pottery occur, have been found to admit of this explanation.

The following animals are frequent in the cavern deposits: most of them are found in the glacial detritus of the same countries; several of them also occur in lacustrine deposits, of various antiquity.

Ursus spelæus.	Rabbit.
—— arctoideus.	Water Rat.
—— cultridens.	Beaver.
Gulo spelæus.	Megatherium Cuvierii.
Wolf.	Megalonyx Jeffersonii.
Fox.	Elephas primigenius.
Hyæna spelæa.	Hippopotamus major.
Felis spelæa.	Rhinoceros tichorhinus.
Hare.	———— minutus.
Horse.	Cervus elaphus.
Boar.	Bos primigenius.
Cervus megaceros.	—— priscus.

The remarkable pachydermal genus *Mastodon* occurs in the crag and other tertiaries of Europe, America, and Ava, but not in caverns.

GLACIAL ACCUMULATIONS.

(SYN. *Northern drift*, Till.; *Terrain de Transport*; *Boulder Clay*, *&c.*)

It is not so much the presence of any particular earthy materials, such as boulders, gravel, &c.,

but the mode of their geographical distribution, and the occurrence in them of the remains of certain tribes of extinct Mammalia, which define the glacial products. The relation of the deposits to the physical geography of the region marks the condition of the watery or icy action concerned; and the natural history of the organic remains determines the relative date of the operations.

When deposits, like those of the glacial era, lie in valleys, we may sometimes refer them to a local origin; but when over wide plains, on hill slopes, and on ranges of high ground we find heaps of rock fragments, and rolled but not river gravel — materials unknown *in situ* in the vicinity, — in situations to which no existing streams could carry them, — where no imagined lakes could leave them, — where, by no conceivable combination of conditions, consistent with the geological history of the country, either ancient streams or lakes could transport them, we are compelled to infer that some other agency has been employed. This was the course of reasoning applied by Smith, forty years ago, to some facts near Bath, and soon generalised by his extensive researches in England; by Buckland, Conybeare, and Sedgwick, to a large class of impressive phenomena in the North of England, in the midland counties, and in the valley of the Thames; by Saussure and De Luc to the scattered blocks of the Alps; by Brong-

niart and others to the travelled boulders of the North of Germany. A case in the North of England appears decisive of the truth of the principle.

The accompanying section (fig. 8.) is intended to show the nature of the country along a line E. S.E. from Shap Fell in Cumberland, to Flamborough Head in Yorkshire, a distance, in a straight line, of 107½ miles, but by this rather bending course, of 110 miles. Shap Fells, elevated about 1500 feet above the sea, consist of porphyritic granite, enveloped in schistose rocks. The slope from these fells, eastward, is soon stopped by a bold escarpment of the lower mountain limestone series, which rises to about 800 feet in height, and slopes eastward under the flat narrow valley of the Eden, running N.N.W., which is full of red sandstone, at the bottom of which are certain conglomerate beds. Immediately above, on the east, is an escarpment of the same lower mountain limestone, thrown up to a great height, and surmounted by other rocks of the same formation to an altitude, in Cross Fell, of 2901 feet; in Shunnor Fell, of 2329 feet; Water Crag, 2186 feet, &c. The lowest part of this ridge, *which opens directly to the west*, is the pass of Stainmoor, 1440 feet, which is almost level with Shap Fells: from hence the slope is almost uniform to the Vale of York, which runs north and south. Beyond rises the oolitic ridge of the eastern moor-

lands 300 to 1485 feet; then follows the Vale of Pickering, 100 feet above the sea; and the section crosses over the chalk wolds, 500 to 800 feet, and ends at Flamborough Head, 150 feet above the sea.

It is found that blocks of the Shap granite have travelled down the slope of their native mountains, over the limestone ridge of Orton, across the Vale of Eden, over the limestone ridge of Stainmoor, down and athwart the whole Vale of York, over the oolitic ridge, — not at the highest points, — and over the chalk hills to Flamborough Head.*

The valley of the Eden is an ancient mesozoic submarine valley defined by elevations of the limestone and slate on either side; the Vale of York has served for the passage of vast bodies of water, which have removed much of its stratified red sandstone, so that the physical features of the country were much the same during the transport of the blocks as at present. But the level of the sea was different. Accumulations marking this level can be traced to about 1500 feet higher than the actual mean height of the tide, and there is little doubt that after the age of the crag and other preglacial deposits a large portion of the northern hemisphere was depressed; the sea

* For details on this and many other instances, read Buckland, Reliq. Diluv.; Conyb. and Phill., Geology of England, Encyclop. Metrop.; Geology of Yorkshire.

currents were altered; the temperature was lowered; and the mountains, though less conspicuous, were overspread with snows, which gave birth to glaciers. These, loaded with detritus and broken off at the edge of the sea, were floated away by the currents in various directions, and dropped their load in different parts of the sea.

The difficulty of distinguishing between glacial and old alluvial accumulations may, in general, be removed by attention to these points: 1st. The rock fragments, or boulders, and smaller masses in diluvial deposits have been generally removed great distances (so that often no rocks of the same kind occur in the drainage of the district), and in directions different from those of existing streams. 2nd. The gravel of these deposits is generally somewhat different in its aspect and manner of attrition from that of old river-courses: it often lies in clay. 3rd. Bones of elephants, oxen, horses, deer, &c., are not unfrequently found in the gravel and clay.

There is good geological evidence that the glacial accumulations are not all contemporaneous—not all the result of one transient agency, but of forces varying in strength and direction, and transporting different materials—clay and pebbles, gravel and sand, in several alternations. But there is such a conformity among the organic remains associated with these deposits, that we are

entitled to say these deposits mark, over large regions, the termination of a certain geological period, defined by the existence, on the dry land, of peculiar, chiefly extinct, races of quadrupeds.

The most remarkable of these remains in England are those of the mammoth, *Elephas primigenius*, (several varieties,) *Hippopotamus major*, *Rhinoceros tichorhinus*, *Felis spelæa*, *Hyæna spelæa*, wolf, horse (large and small species), ox, extinct urus, Irish elk.

POSTGLACIAL ACCUMULATIONS.

Under this head we shall rank a considerable variety of deposits which have happened on the land, at the shores, and in the sea, for the most part at a remote period; but under the same or nearly the same general conditions of land and sea as those which now prevail; the remains of life connected with them are mostly those of species now living in the same regions; corresponding phenomena are still in progress; and we find ourselves brought to the period when geological time approximates to, if it does not really pass, into historical date.

We shall first notice those lacustrine and peaty deposits, which by their contents, timber, or shells, or bones, seem to claim a comparatively high and definite antiquity, immediately following the

glacial period, and then add a few remarks on fluviatile and marine deposits now in progress.

LACUSTRINE SEDIMENTS.

Deposits are formed in lakes from several causes: 1. from the growth of shells; 2. from springs containing carbonate of lime; 3. from mechanical admixtures of sand and clay, and vegetable remains derived from inundations or rivers. Some of these may be of very high geological antiquity; for we may believe lacustrine deposits to have been produced upon the land as soon as it was raised above the sea; and this has been shown to have happened at many different periods. The right way of investigating their antiquity is to study and compare the organic remains imbedded. Thus studied, it is found that all the known *superficial* lacustrine deposits are posterior to the chalk, though many large tracts of land were elevated long before the production of that rock. In England they are nearly all subsequent to the era when the mammoth existed in northern regions.

Mr. Lyell has described the production of shell marl in Bakie Loch, Forfarshire, as depending on calcareous springs, and the growth of Limnææ, Cyclades, &c. It contains seeds of Chara, horns of stags, &c. Almost every trace of shells is sometimes obliterated. Certain springs, especially

in the volcanic regions of Italy and Auvergne, deposit in lakes a great quantity of carbonate of lime. (Geol. Trans., vol. ii., N.S.) The accumulation of fine clay in ponds and lakes may be universally observed. Inclined laminæ of pebbles and sand are swept into the Lake of Geneva by the stormy waters of the Rhone, and deposited in the upper part. In some lakes all these processes go on simultaneously.

It is not easy to point out the real or even the relative antiquity of the various lacustrine deposits not associated with marine deposits now known to geologists. The following attempt is offered with much hesitation. The most recent are placed at the top.

1. Now in progress in many lakes. Italy; Scotland.

2. Old lakes, nearly contemporaneous with submarine forests, containing the bones of the beaver, the wolf, the red deer, and other existing species of animals, and the extinct Irish elk. Holderness; Berwickshire.

3 Lakes of the elephantoidal era, containing bones of the fossil elephant, fossil urus, *Felis spelæa*, *Ursus spelæus*, fox, lagomys, rat, chæropotamus, &c. Weighton in Yorkshire; Gmünd? Oeningen?

4. Lakes of the palæotherian period; lakes of the Cantal, &c. The extinct genera palæotherium,

anoplotherium, and lophiodon, seem to mark a determinate terrestrial geological period, and to establish some points of comparison between this and the ordinary scale of geological chronology, depending on the succession of marine strata and organic remains.

TURF MOORS, SUBMARINE FORESTS, ETC.

In most cases, the submarine forests, as they are termed, lie along the course and near the mouths of great rivers, and are often, perhaps generally, at a level between high and low-water mark, and in a situation where the river sediment, or silt from the tide, has partially covered them. Along the Yorkshire rivers the trees lie generally in a mass of vegetable remains called turf, which occurs at all levels, from about high-water mark to a depth of thirty or more feet beneath it. This surprising spectacle of ancient oaks and firs buried in the earth, in situations where they could not now be made to vegetate, except by the aid of artificial drainage, has not often been carefully described by geological eye-witnesses, and the workmen commonly give but a very confused account of what they have seen. It is by no means certain that in all instances the trees grow where they now appear; the geological era of their growth is sometimes extremely dubious; the ancient condition of the drainage of the

country, in relation to the tide-opening of the estuary, is seldom ascertainable: for these reasons the subject is yet in some obscurity.

In one case, near the Humber, the phenomena are not irreconcilable with a probable view of the ancient state of drainage of Yorkshire, without any intervention of subterranean movements: how far this mode of explanation will apply to other cases, may be a subject of further inquiry. In the meantime we may perhaps believe, from the occurrence of peat-beds in the old lakes on the Yorkshire coast, from the certainty of the drifting of peat and timber in other parts, and from the great analogy of the vegetable deposits, that some very general agency was concerned in the prostration and inhumation, and perhaps drifting, of the trees, whether accompanied by a change of level or not. The trees are oak, birch, fir, hazel, alder, yew, &c. With them lie acorns, fir-cones, hazel-nuts, bones of the horse, ox, stag, fallow deer, sheep, &c. (Phil. Mag. 1834.)

VALLEY SEDIMENTS.

In all valleys through which continuous streams, or periodical or accidental inundations pass, the effects of their mechanical action remain more or less distinctly marked. The erosive power of the currents is conspicuous in all the steeper parts of the sloping valley, which, originating generally in

a convulsive displacement of rocks, has received, in most cases, its peculiar character from the action of water. According to the nature of the rocks the features of the valley vary. In all the lower parts of the valley, and especially towards the meeting of the freshes and the tide, the sediment brought down from the uplands is deposited on the now level surfaces of the marshes and meadows, in floods, or on the bed of the river in the ordinary state of the waters, or carried out to sea.

In many cases, the sedimentary deposits in valleys seem to have little relation to the actual stream. For instance, in the valley of the Rhine, between Strasburgh and Bingen, the deposit called *löss* is found at the height of some hundreds of feet above the river, and seems to have been a very extensive mass, through which, in some cases, the Rhine now works its way. The remarkable terrace-heaps of gravel and sand at the mouth of Glen Roy, and along many other Highland and Cumbrian valleys, is a phenomenon apparently of a similar nature. It seems to prove that these valleys are of high geological antiquity, and that water formerly stagnated in or flowed down them under different circumstances as to level, outlet, and dynamical action from the present.

In some cases the action of rivers, in accumulaing sediment, is so regular as to permit the layers to be counted for terms of years. This is ob-

served on the slopes of the Alps to depend on the periodical melting of the snows.

The organic remains in valley deposits are of such land animals and plants as, lying on the surface, were exposed to the inundation. Land shells are very abundant in the löss of the Rhine valley; along the rivers of Yorkshire, hazel-nuts and trees, bones of stags, land and freshwater shells, &c., occur, and in some instances have undergone petrifaction. (Phil. Mag. and Annals, 1828.)

CORAL REEFS, SHELL BEDS, ETC.

The growth of coral in the warm tropical waters, and along the Australian shores, is one of the most important agencies now at work in altering the face of the globe. Coral reefs are not formed at such enormous depths as was once imagined, but they rise from submarine mountain ridges, from the peaks of old submarine volcanos, along the coasts, and around the islands. In these accumulations the lamelliferous corals bear the largest share; but many shells, fragments of other coral, drifted sand, and many other substances lodged in the reef, are enveloped in its growing mass; and thus islands of living rock slowly emerge from the middle of the ocean, gradually become heightened by the heaping up of the materials broken from their edges or drifted by the sea, covered by trees,

and inhabited by birds and a few other animals. The coral reefs of the Bermudas are described as partly a mass of chalky or granular carbonate of lime, derived from comminuted and decomposed coral, and as taking a form depending partly on the currents of the sea. The elevation above the sea, which some West Indian coral islands assume is ascribed to volcanic action. We have already noticed the opinion, which is gradually gaining ground among geologists, that several of the limestone strata are locally to be regarded as magnificent coral reefs.

In particular parts of the sea the currents drift shell and fishes' teeth, so as to make the seamen remark the fact in their soundings. This is analogous to many cases of the accumulation of shells and shelly fragments in particular parts of the ancient strata.

COAST SEDIMENTS.

The materials brought into the sea by rivers, and obtained from the incessant wasting of cliffs, are not all carried down to the depths, but in a great measure restored to the land, where the coastward currents cease their movements. This happens generally along some low shore, which only just rises above the gradually deepening waters, in some land-locked bay or estuary. The most rapid growths of new land certainly adjoin,

or are influenced by, the mouths of great rivers; but many considerable tracts are only remotely dependent on such influence. It is not so much by the mud which descends with the Ouse, the Dun and the Trent, that the coast of Lincolnshire has been extended, as by the materials brought from the ruined cliffs of Holderness; neither have the sluggish streams which meander through the fens of Cambridgeshire yielded that mass of matter which, since the Roman sway in Britain, has been added to the coast, to the extent of miles, beyond their line of embankment. The case is different along the shore of the Adriatic, where the torrents from the Alps bring such loads of sediment as to promise the eventual conversion of all the northern end of that sea into marsh land. The flatness of these *foreshores* corresponds with the degree of quiescence of the water, and the laminæ, which cover one another successively, are not quite horizontal, but form long inclined planes, sloping seaward.

Storms, or varying circumstances, may produce a temporary derangement of the laminæ, or spread layers of pebbles, or scatter shells over the surfaces. A variety of marine worms may leave their traces, or marine reptiles the prints of their feet; but generally, remains of such animals, of shells, and plants, are very rare in marsh lands formed under shallow waters. In this manner we may conceive

some sandstones of the old strata to have originated; and account for many of their peculiar appearances. The pebble beaches along some parts of the English coast may remind us of the appearance of some conglomerates.

SANDBANKS.

The agitation of the ocean is so unequal, even on the same line of coast, that in some parts sand, in other parts fine clay, in others pebbles, are accumulated, according to the moving force of the water. Generally, the materials which fall from sea cliffs are sorted by the tide; pebbles drop quickly near their original sites; sand moves further; fine clay is transported for leagues along the coast. The sandbanks along many parts of the coast are either stationary or moving, augmenting or decreasing, according to the circumstances of the oceanic currents. Along the east coast of England especially, but everywhere more or less, the submarine sandbanks are cut through by real channels, which might be properly called tidal valleys.

This fact is perhaps analogous to the well-known irregularity of the extent and thickness of many of the ancient stratified sandstones.

Certain modern sandbanks are occupied by weeds, cockles, oysters, or fishes; others not.

This is also to be compared with the very irregular distribution of organic remains in the sandstone rocks.

MODERN ELEVATIONS OF THE SEA-BED.

The geologist must on no account think it out of the bounds of his legitimate province to examine with care and interest into the history of the processes now performed in the ocean and on the land; for it is only by discrimination and generalisation of these that we can hope to draw satisfactory inferences concerning the force and direction of the agencies formerly exerted in earlier oceans, and on earlier continents.

There is, in fact, no hard line of separation between the modern sea deposits and the ancient submarine strata. In some situations the sea-bed has been laid dry, at epochs within the reach of history, by volcanic action at Santorino, in the Grecian Seas; in other cases, at epochs which ascend beyond the existence of mankind, to the era of the mammoth, as in the eastern parts of Yorkshire. The deposits thus exposed to our view wear often characteristics of organic life and mineral aggregation, which are distinct both from those of diurnal occurrence, and from those of the tertiary periods; but as frequently they display intermediate characters, and thus connect the

actual with the past,—the modern reef with the ancient coral rock,—the sediments of to-day with the sandstones of immeasurable antiquity,—the shell and fish banks of our shallow seas with the crag, the lias, and the mountain limestone.

The most frequent examples of such elevations of the sea-bed, are called "Raised beaches." Such occur in Sweden extensively, as at Uddevalla; on the English coast, as near Preston, in Lancashire, and near Filey in Yorkshire; on the Scottish coast, as in the vale of the Clyde, and the valley of the Forth; on the Irish coast, as about Wexford. Similar cases abound on the shores of Europe and America. In the sand or argillaceous deposits referred to, modern shells often occur, and in great numbers, such as Turritella terebra, Cardium edule, Littorina littoralis, &c. Occasionally an extinct species appears among them. The elevation of such deposits above the sea is from 10 to 100, or even 1500 feet.

In judging of the upward extent of these movements of the sea-bed, we shall find the benefit conferred on geology by Professor E. Forbes's surveys of the British and Ægean seas. From his dredgings at various depths we learn that the invertebral life of the ocean may be classed in several zones of depth, and that to each zone some *characteristic* forms of plants or animals, or, in the case of shallow seas, both, may be assigned.

In the Ægean we have soundings to the depth of 1380 feet; and dividing the depth into eight zones, we find the following useful table of characters.*

1. Littoral Zone—to depth of 12 feet; the bottom variable. *Plants,* Padina pavonia. *Animals,* Littorina cærulescens, Fasciolaria tarentina, Cardium edule.
2. Zone from 12 to 60 feet; ground variable. *Plants,* Caulerpa, Zostera. *Animals,* Cerithium vulgatum, Lucina lactea, Holothuriæ.
3. Zone from 60 to 120 feet. Ground muddy or sandy. *Animals,* Aplysiæ, Cardium papillosum.
4. Zone from 120 to 210 feet; ground gravelly and weedy or muddy. *Plants,* Dictyomenia volubilis, Codium bursa. *Animals,* Ascidiæ, Nucula emarginata, Cellaria ceramoides.
5. Zone from 210 to 330 feet. Ground full of Nullipores and shelly. *Plants,* Rityphlæa tinctoria. *Animals,* Cardita aculeata, Nucula striata, Pecten opercularis, Myriapora truncata.
6. Zone from 330 to 474 feet. Ground mostly nulliporous. *Plant,* Nullipora. *Animals,*

* Reports of British Association, 1843.

Venus ovata, Turbo sanguineus, Pleurotoma maravignæ, Cidaris hystrix.

7. Zone from 474 to 630 feet. Ground mostly nulliporous. *Plant*, Nullipora. *Animals*, Brachiopoda, Rissoa reticulata, Pecten similis, Echinus monilis.
8. Zone from 630 to 1380 feet. Ground yellow mud, full of remains of Pteropoda and Foraminifera. *No plants*. *Animals*, Dentalium 5-angulare, Kellia abyssicola, Ligula profundissima, Pecten Hoskynsi, Ophiura abyssicola, Idmenea alecto.

The study of the "ancient sea-margins," as Mr. Chambers justly calls them, which the raised beaches, and the terrace lines of watery action often associated with them, indicate, is one of the most curious parts of modern geology. They are really of all geological ages; and by their help, conjoined with the independent data regarding depths of marine life furnished by such dredgings and such reasonings as those of Forbes in the Ægean Sea, we shall find many parts of the hydrography of the Old World come more distinctly into view, and afford standing points for those philosophical views of the ancient land and sea at successive epochs, to which man is invited by geology.

PART IV.

ROCKS OF IGNEOUS ORIGIN.

PLUTONIC ROCKS.

The rising of new islands out of the sea, composed of lava or scoria, seems to leave no doubt of the propriety of admitting amongst the products of active volcanos submarine currents of lava, spreading over limited breadths of the ocean bed according to the conditions of the efflux. Observation of such effects is not, indeed, to be attempted; but from noticing the appearance assumed by lava which has flowed along the ground, and solidified under sea-water, we learn some of the essential characters impressed upon these rocks by the contact and pressure of water. These characters, conjoined with direct observations on the relations of certain ancient igneous rocks to the adjoining strata, enable us to determine that they were really poured out on the bed of the sea, at intervals during the period occupied in the deposition of those strata.

The occurrence of certain igneous rocks in the

fissures of the mass of a volcanic cone, suggests another principal condition of solidification of melted rock; viz. while surrounded by previously consolidated materials. Among the ancient stratified rocks, igneous rocks occur in the state of dykes, filling fissures, and masses interposed between the strata; and by careful study of the circumstances, no doubt remains that in many instances the fissures were filled by injections of melted rock, and the preconsolidated strata violently separated, so as to admit between them fluid masses of greater or less extent, which have subsequently been consolidated into beds more or less conformable to the original strata.

Hence we have submarine and subterranean pyrogenous rocks, which, as they have both been subject to the influence of pressure, are not always certainly and easily distinguishable.

There is a considerable variety of subaërial volcanic rocks produced at the present day, notwithstanding the general similarity of the circumstances of their extrication; but a far greater variety of mineral aggregates was formerly produced under the sea, or forced into the openings of older strata. It is scarcely possible to arrange these products in the order of antiquity, except in very limited districts; and different districts, compared in this point of view, present very slight analogies. Generally we may, perhaps,

admit the greater antiquity of granite, and the more modern date of basalt, and assign an intermediate period for porphyry and syenite. But these and other igneous rocks have been again and again reproduced at different geological eras. On this account it will be most useful to class the igneous rocks with reference chiefly to their composition and aggregation.

Mineral veins and beds present so many points of agreement with dykes and beds of pyrogenous rock, and so many facts harmonising with the view that they are gradual or sudden effects of heat, operating directly or through the agency of water, that it is probable geologists will at last almost universally agree in regarding them as produced by injection of fluid masses, or by sublimation, or electrical transfer of metallic and mineral particles held in solution under the influence of heat and pressure. For veins of segregation the latter view seems most satisfactory.

GRANITE, PORPHYRITIC GRANITE.

Composition. Essentially contains crystallised felspar, with variable proportions of quartz and mica. The mica is sometimes replaced by talc, or chlorite, and partially by hornblende: in this last case it graduates to syenite.

Some varieties, having large included crystals of felspar, are called porphyritic; others, com-

posed of felspar with angular masses of quartz, are called graphic granite. There is great diversity in the magnitude and colour of the felspar and mica. The quartz is usually gray. Some granite is full of cavities, in which the constituent minerals crystallise in various forms.

Occurrence. In immense masses below all the strata; in interposed beds, or expansions among gneiss or other primary strata; in uplifted masses in contact with ancient and modern strata; in veins ramifying from the great masses into the adjoining rocks.

Localities in Great Britain. Ben Nevis, Glen Tilt, Cairn Gorum, various points in the Highlands, Arran, base of Skiddaw and upper part of Shapfells in Cumberland, Dartmoor, Cornwall, Isle of Man, Mourne Mountains.

FELSPAR ROCK, FELSPAR PORPHYRY, EURITE.

Composition. A basis of uncrystallised felspar, in which crystals of that mineral, with or without crystals of quartz, and rarely mica, are imbedded. Colours, red, gray, green, &c. Some varieties enclose nodules, sometimes almond-shaped, rather than crystals, and are then called amygdaloidal.

Occurrence. In overlying and interposed masses, sometimes columnar; and dykes.

Localities. Glencoe, Ben Cruachan, and other points in the Highlands, Arran, St. John's Vale, Cumberland, Cornwall, North Wales.

CLAYSTONE, CLAYSTONE PORPHYRY.

Composition. A basis of uncrystallised, almost earthy felspar, with or without crystals of glassy felspar, quartz, and rarely mica imbedded. Colour, red, yellow, grey.

Occurrence. In interposed masses and dykes; a prismatic structure prevails in both.

Localities. The Pentland Hills, Arran.

HORNSTONE, HORNSTONE PORPHYRY.

Composition. The difference between this group and that above is in the less fusibility of the basis. It is not common.

Occurrence. In dykes, associated with pitchstone.

Locality. In the Isle of Arran.

PITCHSTONE, PITCHSTONE PORPHYRY.

Composition. A glassy felspathic rock, with or without crystals of felspar and small spherulitic concretions. Colour, green, black, reddish.

Occurrence. In interposed columnar beds and dykes, generally exhibiting a prismatic structure.

Localities. Scuir of Egg, Arran.

SYENITE.

Composition. Felspar more or less crystallised, with crystallised hornblende, and admixtures of

mica, quartz, augite, oxidulous iron, &c. Colour of the felspar, red, white (rarely green).

Occurrence. In overlying masses, and rarely dykes.

Localities. Isle of Skye, Isle of Arran, Charnwood Forest, Carrockfell in Cumberland, Malvern Hills.

HYPERSTHENE ROCK, HYPERSTHENIC SYENITE.

Composition. Felspar more or less crystallised with crystallised hypersthene. Colour of felspar, white, red; of the hypersthene, green, purple.

Occurence. In connection with granite, uplifted masses, and, rarely, dykes.

Localities. Valteline, Isle of Skye, Carrockfell in Cumberland, Radnorshire, Cornwall.

DIALLAGE ROCK, SERPENTINE.

Composition. Felspar and diallage: when crystallised, it is diallage or gabbro; when fine-grained and soft, with indistinct traces of crystallisation, serpentine. Colours various, with metallic reflections.

Occurrence. In overlying masses and dykes.

Localities. Apennines, Pyrenees, Corsica, Cornwall, Scotland.

GREENSTONE, AMYGDALOIDAL GREENSTONE.

Composition. Compact felspar and hornblende

or augite, aggregated together with various degrees of distinctness, from a largely granular to an almost earthy state; sulphuret of iron occurs in it. Colour, green, greyish green, black. Occasionally, nodules of agate, chalcedony, or carbonate of lime, give it an amygdaloidal character. When the felspar is crystallised it is undistinguishable from syenite. The compounds of augite and compact felspar are called augite rock by M'Culloch; of augite and crystallised felspar, mimose by M. Haüy.

Occurrence In interposed masses, often rudely columnar; in dykes.

Localities. In Scotland, especially about Edinburgh; Keswick, Derbyshire (toadstone), North Wales, North-east of Ireland.

BASALT, AMYGDALOIDAL BASALT.

Composition. Basis of augite (or hornblende) and felspar, and often titaniferous iron; a dense compact hornblendic or augitic mass, which yet shows crystallisations of felspar. Olivine often occurs in it; chlorophœite, agate, large crystals of felspar, and nodules of carbonate of lime diversify its aspect. In this way, basalt becomes amygdaloidal; when the felspathic parts are distinct, it passes to greenstone. It is found among the products of modern volcanos.

Occurrence. In vast overlying plateaux, and

interposed stratiform masses, often associated with greenstone; in dykes. A columnar jointed structure belongs very generally to this rock. Some dykes of basalt in the North of England are from twenty to sixty miles long.

Localities. The North-east of Ireland; Scotland, especially near Edinburgh; North of England, especially Teesdale, Durham, and Northumberland; near Dudley.

MELAPHYRE, BLACK PORPHYRY.

Composition. Basis of black augite, with crystals of felspar.

Localities. In uplifted masses. Along the southern flanks of the Alps.

WACKÉ.

This rock resembles decomposed basalt or claystone; and in some cases may really be composed of particles of disintegrated igneous rocks, or of ashes ejected by ancient volcanic action, and subsequently united by aggregation in water. This seems to have been the origin of the bedded wacké of the Calton Hill, Edinburgh; the same explanation has been some time since proposed by Murchinson for certain local sandstones in the Silurian system of Shropshire, &c. De la Beche entertains the same opinion as to some variable rocks about Brent Tor, in Devon; and in the

parts of Wales about Cader Idris. The same view appears applicable to the dark basaltoid sandstones of Oban. Wacké is usually traversed by strings, and filled with nodules, of calcareous spar, chalcedony, quartz, &c. It then becomes what is ordinarily called amygdaloid.

Occurrence. In overlying masses and interposed beds.

Locality. Calton Hill, Edinburgh.

VOLCANIC ROCKS.

EJECTED IN THE STATE OF ASHES.

Subaerial. These are either blown into the air by the explosive gases and vapours which accompany a volcanic eruption, and fall as dust, ashes, scoria, and stones; or poured out in a stream of melted rock from the summit, or more generally the flanks, of the volcano. In consequence of the explosive force being directed nearly vertically, and the ashes falling on all sides equally round the aperture, the hills of scoriæ, ashes, &c., accumulated round a volcanic vent, are always conical. Whether lava currents issue from the apex or the side, they merely cause a slight irregularity in the figure; but a new explosive vent opening toward the base of the mountain may throw up a new hill. Thus several cones on the flanks of Ætna have been thrown up.

Subaqueous. Heavy rains often accompany volcanic eruptions. These may sweep down the falling clouds of ashes to some plain or other repository in enormous quantities: thus, probably, the city of Herculaneum was buried, while Pompeii and Stabiæ were overwhelmed with dry ashes. The volcanic ashes deposited in lakes and hollows form what is called volcanic tuff; at Naples, puzzolana; on the Rhine, trass. The loose stones, scoriæ, ashes, &c., thrown into the air by a volcano, are generally of the same mineral composition as the lava currents, and are probably derived from the melted rocks within the crater, acted on by steam and gaseous expansion. It is evident that such ejections may happen from beneath the sea, or lakes, but the depth of the ocean and other circumstances seldom permit their appearance. The short-lived island of Sciacca, on the Sicilian coast (1831), threw up a vast heap of scoriæ, &c., probably from a depth of above 100 fathoms in the sea. These loose materials, subsequently agitated in the water, and collected on the bed of the sea into irregular strata, will, probably, constitute a marine puzzolana, or volcanic sandstone, which may or may not contain marine shells.

MELTED ROCKS.

The lava currents (*coulées*) which issue from a burning mountain are completely fluid mineral compounds, which, according to circumstances affecting them after their eruption, solidify into glassy, cellular, compact, or crystalline rocks. Rapid cooling of lava leaves it a glass; slow cooling, a crystalline rock; gaseous extrications make it a cellular mass. It is found that lava solidified under water, that is, under the *pressure* of water, is less cellular and more dense than parts of the same current which were indurated in the air. Hence we see that the *rate of cooling* and the *degree of pressure* control in a remarkable degree the condensation of lava, and determine some of its most general characters.

The chemical composition of lava is generally such as to give origin to abundance of glassy felspar, or of augite with felspar. The former is composed of silica, 63—69; alumina, 15—17; potash, 13—15. The latter of 50 silica, 24 lime, 12 to 28 oxide of iron, &c. As an intermediate case, the compact lava of Catania and Calabria yields 51 silica, 19 alumina, 10 lime, 4 soda, 14 oxide of iron, 1 muriatic acid. Basalt is an augitic lava, generally consisting of 46 silica, 16·5 alumina, 9 lime, 20 oxide of iron, and 3 or 4 soda. Trachyte is a felspathic rock. Between trachyte and

basalt are innumerable varieties, depending on the proportions of augite and felspar, and on the admixture of olivine, oxide of iron, hornblende, quartz, and many other minerals.

Many volcanos have yielded, as superficial products, both basalt and trachytic lava; but the far greater portion of basaltic rocks has been formed in subterranean or subaqueous sheets, and subsequently elevated with the strata; the same is supposed by some writers to be the case with the trachytes of the Puy de Dôme and some other localities.

SITUATIONS OF ACTIVE VOLCANOS.

In European Islands and Sea-coasts. Ætna, Vesuvius, Stromboli, Vulcano; several in Iceland; Jan Mayen, Santorino.

In African Islands. Teneriffe, Lanzerote, Cape Verd Isles, Azores, Isle of Bourbon, Madagascar.

In Asia. On the Continent: Demavend, Kamschatka. In the Islands: Zibbel Teir (Red Sea), an Island in the Sea of Azof, Aleutian Islands, Kurile Islands, Japan, Loo Choo, Formosa, Luçon, Fugo, Mindanao, Celebes, Ternate, Fidore, Sumbawa, Java, Sumatra, Barren Island, Banda, New Guinea, New Britain, New Ireland, Friendly Islands, Society Islands, Ladrone Islands.

In America. The Continent: North California,

Mexico, Nicaragua, Guatemala, Colombia, Peru, Chili. Islands: West Indian Islands, Galapagos.

PRINCIPAL CIRCUMSTANCES OF VOLCANIC ACCUMULATIONS.

1. Volcanic ashes, scoriæ, and ejected stones, forming the cone of the crater.

2. Volcanic ashes, and other ejectamenta, accumulated by rivers and in lakes.

3. Lava currents solidified on land, in lakes, or in the sea.

These deposits may alternate.

On the subject of volcanic phenomena consult Daubeny's General Treatise on Volcanos.

METALLIC DEPOSITS.

Composition. Almost indefinite. In particular tracts of country certain metals occur abundantly, either native, alloyed, or united with sulphur, oxygen, and acids; and singly, or in connexion with other metals. Certain associations of metallic substances are known; as of iron and copper, lead and zinc, tin and copper. It generally happens that sulphurets occur together; carbonates, phosphates, arseniates, &c. together. It is seldom that metallic matters occur unmixed with rock minerals: these are sometimes characteristically associated with certain metals.

Occurrence. Very rarely in anything like beds.

(This happens to ironstone, which is an aqueous deposit of carbonate of iron.) Most commonly in veins which fill far-extended vertical or inclined fissures of the preconsolidated rocks, and in other veins which are contemporaneous with the rocks. In some veins (Pl. IV. fig. 12. *v.*) (rake veins) the metallic substances mixed with various rock minerals, all crystallized more or less distinctly, form vertical plates more or less regular, the different ingredients alternating. In other veins (pipes) the metallic and rocky substances are vertical or nearly so, but restricted to narrow angular spaces, not fissures, in the rocks. The particular rock minerals associated with metallic substances in veins, receive the name of matrix or veinstuff: they vary, perhaps, in some real relation to the period of their production, and to the nature of the containing rocks, but a certain independence of local character seems always to be recognised. In Cornwall, and the slate districts of Wales and Cumberland, quartz is a common matrix; in the limestone tracts of Derbyshire and Alston Moor, carbonate and sulphate of barytes, and fluor spar, abound; the metallic substances sometimes lie in soft earthy veinstuff, as at Greenhow Hill, Yorkshire, and in Cornwall.

Metallic veins are not confined to any particular tracts of country or any particular age of rocks, but yet they are by far most abundant

along the lines and about the centres of mountain elevations, and in strata of high geological antiquity. No metallic vein has yet been worked in the British islands in strata above the saliferous system. In almost every instance their origin is somehow related to convulsive movements within the earth, and to the development of igneous rocks. In the Pyrenees and Central France, the metallic veins are chiefly confined to a narrow zone round the granitic and other pyrogenous rocks, and are there produced in strata of various antiquity. Rock dykes and metallic veins differ only in the nature of their contents; they have great analogies of origin, but it is rare to find the rock dykes yield metallic treasures. In some granitic districts, as Cornwall, metallic matters have been aggregated by water from the decomposed masses of the rock. Thus tin, and gold in grains and "nuggets," have been obtained by washing the gravel of streams. As from early times in Scythia (Oural), so now in California and Australia, the ruins of quartzose and granitic hills, collected in hollows, are yielding no small store of gold.

There is a remarkable general fact concerning mineral veins, viz. that the most prevalent direction of those which are productive of metallic treasures is from west to east nearly. This obtains in the North of England and Derbyshire,

in Wales, Cornwall, Saxony, and most parts of Europe, and in Mexico. Other directions are also characteristic, as from north to south; but veins in these lines are often less productive, and are generally supposed to be of less ancient date, because they *cut through* the east and west veins. These latter are called right-running veins, the former cross-courses.

In the mining districts of the North of England, the cross-courses are parallel to the dislocations along the Penine chain; the right-running veins are nearly parallel to the two great faults which pass from that chain to the east along the river Tyne and through Craven. This dependence of the direction of the veins upon that of the great lines of convulsion is in harmony with observations in other mining districts, and with the theoretical deductions of Mr. Hopkins.

Another problem of great interest in the reasoning on the origin of mineral veins, is their relation to the divisional planes or joints of rocks. In the vicinity of Aldstone Moor, and parts of Yorkshire, the right-running veins and cross-courses seem to be nearly coincident with the predominant joints and fissures, one set of which runs nearly E.N.E., another nearly N.N.W. In Derbyshire the joints and principal veins form, according to Mr. Hopkins, an angle of 25°. It is desirable that this problem should be accurately

examined in different districts, among rocks of different kinds and ages, and under different circumstances of position.

Metallic matters are often found in the substance of the rocks bordering a vein, in sparry nests and cavities, and in the hollows of shells. These facts, combined with analogous results of operations still in progress, indicate a transfer of the metallic substances by electrical or other subtle agency, even through a considerable mass of rock.

Electricity, probably excited by unequal temperature or chemical action, circulates along many mineral veins. In the *Philosophical Transactions* for 1830, are the results of Mr. Fox's experiments on this subject.

Localities. Common in the primary rocks of the Highlands, Cumberland, Westmoreland, North Wales, Cornwall, Wicklow, Mourne Mountains, Isle of Man, &c. In the carboniferous limestone of Scotland, Northumberland, Durham, Cumberland, Lancashire, Yorkshire, Derbyshire, North Wales, South Wales, Somersetshire. Rarely in the magnesian limestone of Northumberland, Yorkshire, and Nottinghamshire.

EXPLANATION OF A FEW GENERAL TERMS.

Azoic—without life, from α, privative
Cainozoic—recent life, from καινος, recent
Mesozoic—middle life, from μεσος, middle
Palæozoic—ancient life, from παλαιος, ancient
Protozoic—first life, from πρωτος, first
Hypozoic—below life, from ὑπο, under

ζωη life.

Eocene—from ηως, the dawn
Meiocene—from μειων, less
Pleiocene—from πλειων, more
Pleistocene—from πλειστος, most

καινος, recent.

Pyrogenous—originating of fire, from πυρ, fire, and γεν, the radical of words implying origin, &c.
Hypogenous—originating below, from ὑπο and γεν.
Plutonic—rocks originating below, by the agency of heat.

Anticlinal—inclined or dipping from an axis, αντι, against, and κλινω, to incline.
Synclinal—inclined or dipping towards an axis, συν, together, and κλινω, to incline.

Pœcilitic—variously-coloured, variegated, a term applied to the red and blue marls, ποικιλος, various.

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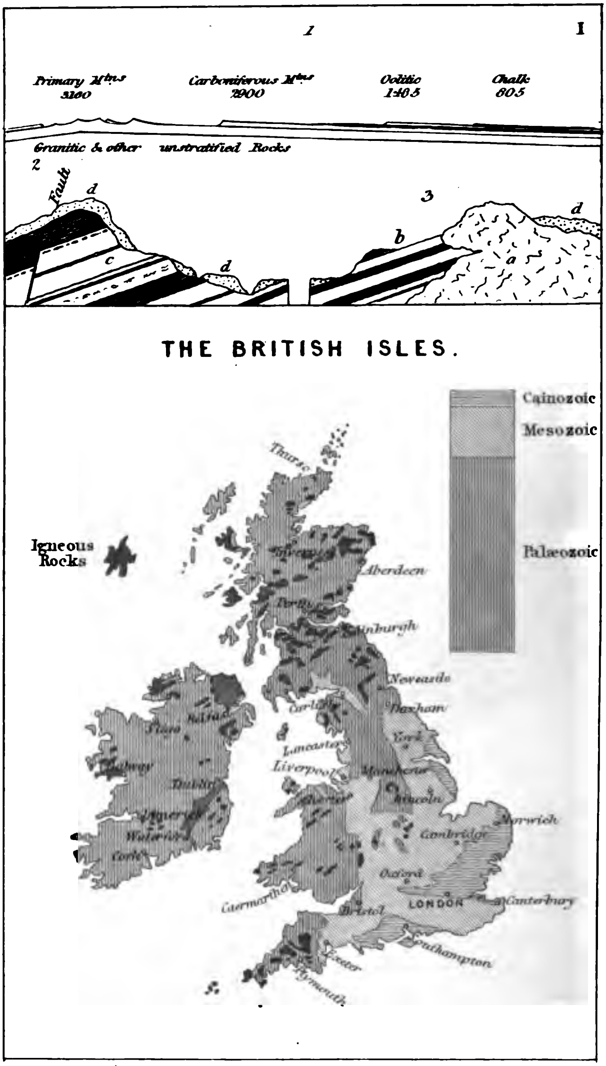

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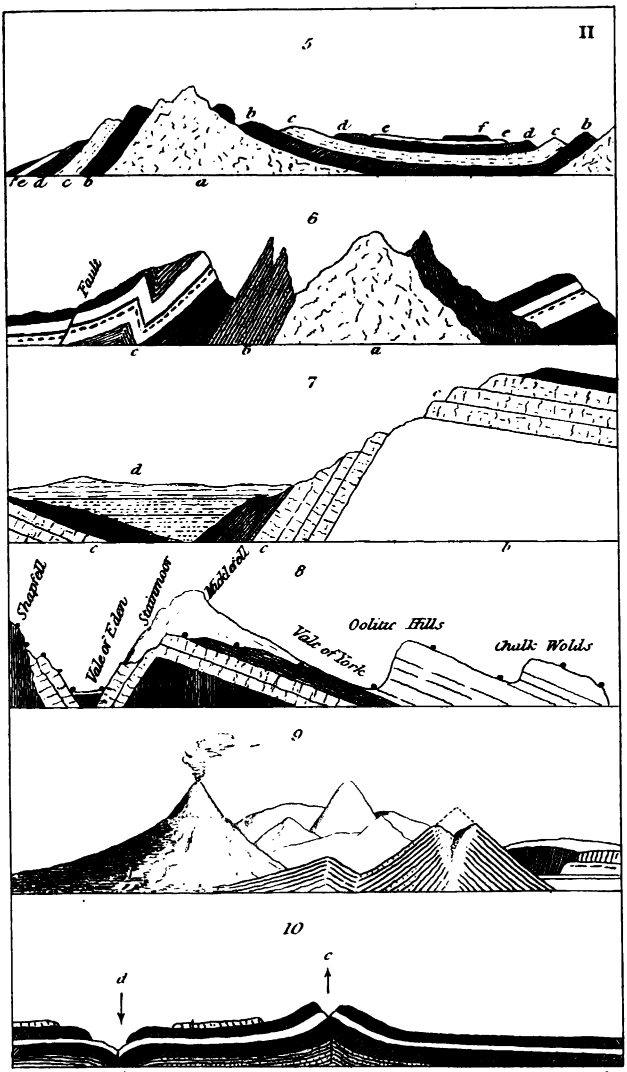

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J. W. Lowry, sculp.

REFERENCE TO THE PLATES.

PLATE I.

Fig. 1. Shows the real proportions of the height of ground above the sea level from Bridlington to Whitehaven: the lines drawn sloping from west to east mark the depth to which the systems of strata descend in that country.

2. This section shows the distinction, as to arrangement, between the superficial deposits (*d*) and the inferior strata (*c*). A dislocation, or fault, affects the latter.

3. Here the stratified rocks (*b*) are contrasted with the unstratified rocks (*a*), and the superficial deposits (*d*).

4. A Geological Map of the British Isles, to show the relative extent of the great groups of strata, and the principal masses of igneous rocks.

PLATE II.

5. From the axis of crystalline rocks (*a*) the strata (*b*, *c*, *d*, *e*, *f*) decline on both sides; those which rise highest on the mountains sink lowest under the plains.

6. Near the axis of crystalline rocks (*a*) the stratified rocks are thrown into great and almost inexplicable confusion of dip, broken by faults, and bent in violent curves. (Alps.)

7. After the occurrence of the convulsions which displaced the formation (*c*), marine strata (*d*) were deposited level on the edges and slopes of the previously disturbed rocks.

8. Shows the course of the Shap-Fell granite boulders across three vales and three abrupt ridges of hills, a distance of 107 miles.

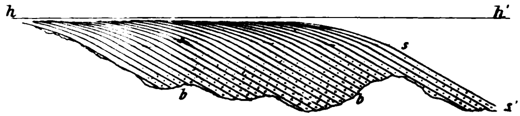
9. Aspect of a volcanic cone, and section of its concentric layers of scoriæ, &c.
10. Effect of local depression (*d*) and of local elevation (*e*).

PLATE III. (FRONTISPIECE.)

This geological view of the Isle of Wight, comprising a plan and elevation of the surface, the natural section of the South Cliffs, and an ideal section through the middle of it, is designed as an instructive example of the relations between the superficial and the interior or subterranean arrangement of stratified rocks. Minute topographical accuracy was not essential for this object, yet the leading physical features of this remarkable island are not ill represented by the lines which pourtray its geological structure. While the northern half of the island, consisting of tertiary formations, partly marine, partly lacustrine, extends into a low triangular space, the southern portion, formed of secondary strata, swells into boldly undulated ridges, which are abruptly truncated by the sea.

From the pinnacles of chalk in the west, called "The Needles," to "Culver Cliff" in the east, is the line of a remarkable dislocation, which has thrown the lower tertiary beds and the chalk from a horizontal into a vertical position. In the drawing the island is supposed to be cut through by a broad channel passing nearly north and south, and exposing on one of its sides a complete section of all the strata, in their real order and arrangement. It is there seen that both to the north and the south of the line of vertical strata the rocks recover their nearly horizontal position; further, we remark the Wealden formation rising into the imaginary cliff in the form of an arch, which agrees with the appearance of that formation both in Brixton Bay to the west, and Sandown Bay to the east, in a kind of "saddle," parallel to the line of vertical strata before mentioned.

fig. 11



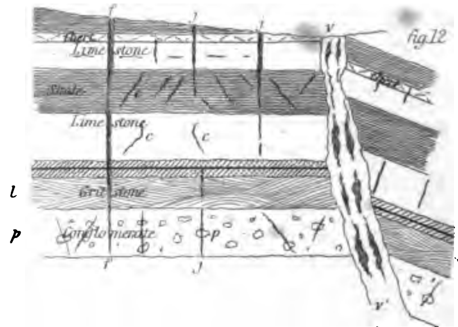
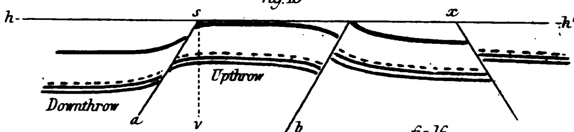
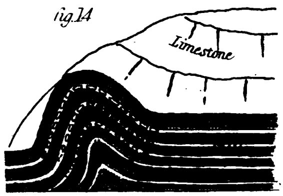


fig. 13





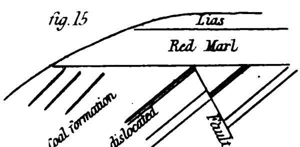
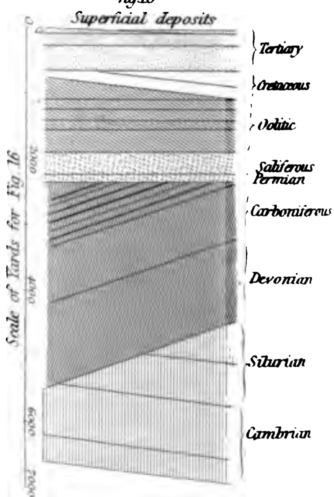


fig. 17

fig. 16



Prof. Phillips delin.

J. W. Lowry Sculpsit

Drawings of this nature are peculiarly useful, and there are few interesting geological tracts to which they are inapplicable: in many instances, especially in mining and coal districts, it will be proper to construct them upon the principles of isometrical perspective, as proposed by Professor Farish, and developed with much ingenuity and practical skill in Mr. Sopwith's recent Treatise.

The letters *h*, *l*, *g*, &c., mark the strata.

h, Hastings Sands, or Wealden formation.

l, Lower Greensand, nearly horizontal in the southern cliffs, rising thence towards the north, and passing inland, over the Hastings Sands, and returning to the cliffs near Culver and the Needles, with a steep dip northward.

g, Gault, ranging parallel to and above the Lower Greensand.

u, Upper Greensand, forming the highest points of some of the southern cliffs; then ranging inland, and returning to the cliffs, and dipping north under the chalk of the Needles and Culver.

c, Chalk, in ramified and detached high masses or downs on the surface, dipping very steeply to the north at Culver, and acquiring at the Needles almost a vertical position. The flints which lie in the upper part of the chalk near the line of dislocation are in a singular condition, penetrated by secret fissures, so as to fall to fragments on being removed from the rock.

t, The Tertiary Strata. Of these the London clay, and a great variety of coloured sands, with mottled clays, beds of lignite, and layers of pebbles, are placed directly vertical at Alum Bay, north of the Needles, while the upper beds of the sandy series turn under the horizontal freshwater marls and limestones of Headen Hill, which is a little further north.

PLATE IV.

Fig. 11. Illustrates the simplest case of the sloping layers

of detritus round the place where a rapid river enters a deep and quiet lake: *h*, *h′*, the surface of the water; *s*, *s′*, the slope of the layers, becoming straight in the lower parts; *b*, *b*, the bed of the lake. It is probable that the matter in these laminæ grows coarser toward the bottom, so as to give somewhat of horizontality to lines of similar ingredients.

Fig. 12. This figure is proposed as an example of the relations of symmetrical structures and dislocations to the planes of stratification; *c*, cracks; *f*, fissure; *j*, joints; *v*, a vein passing through a series of different sorts of stratified rocks. Fissures and joints seldom deviate much from a plane rectangled to the strata (small joints are sometimes oblique in shales); cracks are less regular; vein-fissures are of unequal breadth, and are unequally productive in rocks of different nature. *l*, shows the relation of oblique lamination to true stratification; *p*, the pebbles of a conglomerate divided by the cracks and joints.

13. The relation of faults to planes of stratification is here shown.

14. Contorted strata: near such the rocks are usually full of cracks, and these in limestone are often sparry.

15. Illustrates in a vertical section the meaning of unconformed stratification, the coal measures having been elevated and dislocated, so that the red marl and lias were deposited on their displaced edges.

16. A general section of the strata, showing the principal cases of unconformity in the British Islands.

17. A case of cleavage planes occurring in fine-grained beds of argillaceous rock *s*, *s′*, *s″*; but not in the coarser beds *g*, *g′*, *g″*. The cleavage planes dip 85° from the vertical, and in the same direc-

tion, though the beds are contorted. A joint, *j*, crosses the fine-grained beds *s*, *s'*, *s''*, at an angle of 57°, and the coarse-grained beds at 77°, which is the angle of inclination of many lesser joints in *g*, *g'*, on the plane of the bed; these lesser joints never entering the beds *s*, *s'*, *s''*, as the cleavage of these beds never enters *g*, *g'*, *g''*. This interesting case occurs at Aberystwith.

THE END.

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